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THE TOURMALINIC SILVER-LEAD TYPE OF ORE DEPOSIT.[1]

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It is the purpose of this paper to describe a newly recognized type of ore deposit, namely, the tourmalinic silver-lead type. Ore deposits of this kind have been important producers in the Helena mining region, in western Montana, having yielded $50,000,000 or more.

GEOLOGIC ENVIRONMENT.[2]

General Statement.—The dominant geologic feature of the Helena mining region is the large granite mass which forms the northern extension of the great intrusion known as the Boulder batholith. This body of granitic rock was intruded, so far as is now known, in post-Jurassic and pre-Oligocene time, and is in all probability of late Cretaceous age. The cover under which the granite cooled was largely stripped off during the prolonged erosion of the Tertiary period and the granite laid bare, so that now it forms the prevailing surface rock of the region.

As a consequence of the granite invasion a series of ore deposits, the principal source of the metallic wealth of the

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] Based upon a report by the writer entitled "Ore Deposits of the Helena Mining Region, Montana," Bull. U. S. Geol. Survey No. 527 (in press).

region, was formed around the margin of the granite and in the roof rocks covering the granite. Some of the mining districts whose ore deposits are genetically related to the intrusion of the Boulder batholith are Wickes, Helena, Rimini, Elkhorn, and, preeminently, Butte.

The Roof Rocks of the Batholith.—The remnants of the roof beneath which the granite came to place consist principally of andesitic and latitic rocks, comprising a bedded series of lavas, breccias, and tuffs, with some interstratified quartzite, shale, and limestone. At most localities the volcanic portion predominates. On both the eastern and western borders of the batholith the andesitic rocks are also present in great volume.

Southwest of Elliston the andesite breccias at the base of the andesite series are interstratified with sedimentary rocks, principally the cross-bedded semi-quartzitic sandstone that overlies the Ellis formation, of Jurassic age. A certain amount of conglomerate and limestone occurs with the sandstone, and the conglomerate contains some andesite fragments. Between the andesite lava sheets were found thin intercalated beds of fossiliferous limestone, in appearance like those underlying the andesites. Dr. T. W. Stanton reports on the fossils:

"This lot consists of drab fresh-water limestone containing poorly preserved undetermined ostracods and gasteropods. The age is probably Cretaceous."

This provisional age-determination is the most definite yet available.

The original thickness of the volcanic series is unknown; the maximum thickness, so far as yet determined, is 2,000 feet as exposed southeast of Elkhorn.[1] The rocks have been subjected to erosion ever since early Tertiary time, however, so that it is not possible to determine what part of the original thickness this 2,000 feet represents. Moreover, an unknown volume of sedimentary rocks probably overlaid the andesites. From these considerations it follows that the thickness of the roof under which the granite was intruded, which is an important quantity

[1] Oral communication by Mr. R. W. Stone.

in questions of ore genesis, is not known. Barrell,[1] on the other hand, believes that at the time of its intrusion the granite at Elkhorn, on the margin of the batholith, "was covered by not much over 2,000 feet of andesite rocks, or perhaps less." When Barrell wrote it was not known, however, that sedimentary rocks as well as volcanics formed part of the cover of the batholith.[2] If this estimate of a thickness of 2,000 feet for the batholithic roof be accepted, the conclusion follows logically that many ore deposits of the region, which belong to Lindgren's deep-zone group, were formed at depths far less than 2,000 feet; some in fact at less than 500 feet.

The Quartz Monzonite.—The granite area of the Helena mining region, as already stated, is the northern part of the great intrusive mass extending uninterruptedly from the Highland Mountains, 16 miles south of Butte, to Mullan Pass on the north. This large intrusion was named the Boulder batholith by Weed, from the name of the mountains throughout which it is exposed.[3] It occupies an area of approximately 1,100 square miles, extending 60 miles from north to south and averaging 18 miles in width.

The prevailing rock is a coarse granitoid composed essentially, in the order named, of plagioclase, orthoclase, quartz, biotite, and hornblende. Considered broadly, it is remarkably homogeneous in composition. A widespread feature, extending more or less persistently from Mullan Pass at the northern end of the batholith to Butte near the southern end, is a rough porphyritic habit due to the development of large imperfect phenocrysts of orthoclase.

Under the microscope rock from different parts of the batholith shows essentially similar features. A zoned plagioclase near labradorite ($Ab_{50}An_{50}$) is found to be the dominant feldspar; the most calcic variety (from Elkhorn) as measured on the core

[1] Barrell, Joseph, "Geology of the Marysville Mining District, Montana," Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 166.

[2] *Op. cit.*, p. 167.

[3] Weed, W. H., "Granite Rocks of Butte, Mont., and Vicinity," *Jour. Geology*, Vol. 7, 1899, p. 737.

being $Ab_{45}An_{55}$ and the least calcic, $Ab_{55}An_{45}$—a remarkably narrow range in composition. Orthoclase and quartz are present in abundance and lie interstitially between the idiomorphic plagioclase crystals. Biotite and hornblende are the ferromagnesian minerals and the biotite commonly predominates. At Elkhorn a small amount of augite is intergrown with the hornblende, but does not occur elsewhere. The accessory minerals are magnetite, titanite, apatite, and zircon. The computed mineral composition of quartz monzonite from Clancy is 41.58 per cent. plagioclase, 18.90 per cent. orthoclase, 19.86 per cent. quartz, 8.94 per cent. biotite, and 7.26 per cent. hornblende, together with a few per cent. of minor constituents.

Aplite is a common rock within the area of the Boulder batholith and around its margin. It forms dikes and irregular masses, some of which attain a size of several square miles. The largest of these occurs east of Corbin, but other extensive areas of aplite were noted west of Jefferson and on the ridge south of Red Mountain. Estimated roughly, the aplite forms 5 per cent. of the surface exposure of the batholith. Although aplite is so abundant, pegmatite is of rare occurrence.

The border of the batholith is at many places fringed with aplite, usually tourmaliniferous, lying between the normal quartz monzonite and the invaded rock. Dikes of aplite also penetrate the rocks that enclose the batholith. They are particularly abundant near Wickes, where they occur as persistent dikes, up to 200 feet in thickness, traversing the andesites.

The aplites are fine-grained, granular, white rocks composed essentially of orthoclase and quartz, together with a minor to insignificant amount of biotite. Certain coarsely granular masses show a normal granitic texture and should be termed alaskite. The typical aplites show under the microscope a panidiomorphic aggregate of orthoclase, somewhat perthitic, and quartz, with subordinate plagioclase and biotite and accessory magnetite, titanite, and apatite.

The aplites are commonly tourmaliniferous, but it is usually difficult to determine whether the tourmaline is an original con-

stituent or was subsequently introduced. At a number of localities, however, the tourmaline seems to be clearly of pyrogenetic origin and not connected with fractures or jointing. South of Montana City there occurs a considerable body of aplite carrying nodules composed of tourmaline and quartz, which are scattered throughout the rock with some regularity. The nodules range from a fraction of an inch up to several inches in diameter, and from regular spheroids to most irregular blebs. The inclosing aplite is a snow-white rock, completely devoid of biotite, which as a rule is present to the extent of one or two per cent. in the other aplites of the region. Under the microscope the aplite is found to be of normal composition and texture; in the tourmaliniferous portion the tourmaline, which is an iron-rich variety, is intergrown in poikilitic fashion mainly with quartz, but in part also with orthoclase.

Similar tourmalinic nodules occur in the aplite at Elkhorn and have been described by Barrell.

Post-batholithic Rocks.—A series of dacites comprising lavas, breccias, and tuffs, locally 2,400 feet thick, rest on the deeply eroded surface of the granite and andesite. In the southwest corner of the region they form part of an extensive area extending to Butte and forming Big Butte at that city. They were poured out contemporaneously with the deposition of the lake beds west of Butte and are of upper Miocene age.

Rhyolites also rest on the eroded surface of the granite and the older rocks. Their relation to the dacites was not determinable. They were erupted on a surface whose relief was much like that of the present topography, and are apparently the youngest bedrock formation in the region. At the head of Tenmile Creek in the Rimini district they have been mineralized and constitute low grade gold ore.

THE ORE DEPOSITS.

General Character.—The ore deposits of the Helena mining region fall into two distinct groups, widely separated in time of origin. The older are late Cretaceous or early Tertiary in age, the younger are post-Miocene.

The older ore bodies are mainly silver-lead and gold-silver deposits. In metallic content they contrast strongly with the ores of the nearby Butte district, which are predominantly copper ores, though siliceous silver ores were formerly of importance. The scarcity of copper deposits in this region is a notable feature, doubly so from the fact that the deposits belong to the same metallogenetic province as those of Butte; they were formed at approximately the same time and presumably from the same magma.

The ore bodies of the older group have furnished the preponderant part of the production of the region, in fact the value of their output has been roughly three times that of the post-Miocene deposits.

The silver-lead deposits constitute the prevailing kind of ore body of the Cretaceous deposits. They are commonly situated near the contact of the granite and the rocks invaded by it. Hence they are as a rule inclosed in andesite or granite. The ore bodies are replacement fissure lodes containing galena, sphalerite, pyrite, and arsenopyrite.

A striking feature of many of the ore deposits of the earlier group is the abundance of tourmaline in them. This mineral, as is well known, is of comparatively rare occurrence in ore deposits other than tin lodes. It is found associated, to some extent, with gold ores at various localities and with gold-copper ore, notably in Chile. It is therefore of some interest to find that tourmaline is a common gangue and metasomatic mineral in the ores of this region.

The ores include varieties differing widely in their mineralogic character and metallic content. On this basis three types can be distinguished:

1. Tourmalinic silver-lead.
2. Tourmalinic silver-copper.
3. Tourmalinic gold.

It is with the tourmalinic silver-lead deposits as constituting a newly recognized type that we are here particularly concerned.

Tourmalinic Silver-lead Deposits.—The silver-lead deposits

are the most important group of the tourmalinic lodes; they have given rise to the largest number of mines and have yielded the greatest metallic output. This is the more noteworthy, in that they constitute a group of ore deposits, unique so far as shown by the literature of economic geology.

They are developed most strikingly at Rimini—a mining camp 17 miles southwest of Helena—where tourmaline forms the dominant metasomatic mineral of the ore at certain mines, notably the Lee Mountain and the Valley Forge. At Wickes, the Alta lode, which has been by far the most productive ore body in the region, shows pronounced tourmalinization. Other lodes in the Wickes district, such as the Comet and Gregory, in which the tourmalinization was feeble, are probably end members of the same type of deposit. Finally, the tourmalinic silver-lead type is represented at Elkhorn by the Queen mine.

The deposits at Rimini afforded a better opportunity for examination than those at other localities, and their characteristics will accordingly be presented in some detail.

The lodes at that locality are enclosed in quartz monzonite of uniform composition, which is quite similar to that prevailing throughout the Boulder batholith. A pronounced system of jointing that tends N. 85° E. and dips 80° S. traverses the quartz monzonite. The joints as a rule are widely spaced, and are remarkably plane and parallel. Locally they are closely spaced, as at the falls of Beaver Creek, above the town of Rimini, and the joint faces are coated black with a thin felt of tourmaline fibers.

The ore bodies of the district conform in direction to this system of jointing. The ore occurs in chambers or shoots scattered through a zone which in extreme cases attains a width of 50 feet. In this zone the granite is profoundly altered by sericitization and is strongly impregnated with metallic sulphides. Commercial ore consists of a heavy sulphide aggregate, composed principally of galena associated with sphalerite and pyrite. Arsenopyrite in small amount is a ubiquitous constituent; tetrahedrite and chalcopyrite occur rarely. The ore is more or less

mixed with metasomatically altered granite, but not with vein quartz or other gangue material common in fissure-filled veins.

The ores carry silver in the ratio of approximately 2 ounces to each per cent. of lead, and gold up to $11 a ton in high-grade ore.

The characteristic feature that distinguishes these deposits from the usual types of ore body is that they are accompanied along one wall or the other by what is locally termed a ledge of black quartz. This ledge consists of a coal-black rock composed essentially of an intergrowth of quartz and black tourmaline. In places the grain of this quartz-tourmaline rock is so dense that the tourmaline is not discriminable and the rock resembles a black jasperoid; in other places, however, the grain is coarser and the radial fibrous structure of the tourmaline is readily apparent. Other phases of the tourmalinic rock show a mottling due to small patches of vitreous quartz; this phase, it is perhaps of interest, resembles some of the so-called capel accompanying the cassiterite lodes of Cornwall, as determined by direct comparison with a specimen of capel (a quartz-tourmaline rock) from the 2,800-foot level of the Dolcoath mine, Cornwall.

In places the quartz-tourmaline rock is roughly banded, owing to the presence of intercalated slabs of sericitized granite. This banded phase indicates clearly how the tourmalinic ledge originated. The black tourmalinic bands are seen to merge, by diminution in the amount of tourmaline, into sericitized granite. The tourmalinization evidently proceeded from joint planes in the granite; where the jointing was closely spaced or the tourmalinization was intense, the granite was altered completely and solidly to a quartz-tourmaline rock. In this way black tourmalinic ledges were formed, which are extremely dissimilar to the granite from which they were derived, and which attain a maximum thickness, so far as observed, of 8 feet. It is noteworthy that the most productive lodes are accompanied by the thickest ledges, although on the other hand, ore does not occur continuously along these ledges. The tourmalinic rock carries a variable amount of metallic sulphides, among which arsenopyrite predominates, followed by pyrite, sphalerite, and galena. Locally

it is brecciated and traversed by thin veinlets of quartz and arsenopyrite.

Black, dense, almost jasper-like, tourmaline rock from the Valley Forge mine, as shown by microscopic examination, is composed of quartz and tourmaline in approximately equal amounts. The tourmaline is a brown variety and is present in granular, columnar, and acicular forms. Other minerals found are arsenopyrite, pyrite, sphalerite, galena, sericite, and apatite.

The ore bodies occur in shoots alongside the tourmalinic ledge matter. There is, however, a complete though abrupt gradation between the tourmaline rock and the ore material. The ore favors the sericitically altered granite. A certain definite tendency of the sulphides to segregate during deposition is therefore evident, galena-rich ore tending to develop most abundantly in the sericitic zone of alteration.

That the development of the sulphides and the tourmalinization were contemporaneous is proved by the mutual intergrowth of the sulphides with the tourmaline. Other evidence is the fact that the granite, where traversed by quartz-tourmaline veinlets that are themselves devoid of metallic sulphides, is, nevertheless, in the zone adjoining the veinlets, tourmalinized, sericitized, and impregnated with arsenopyrite, pyrite, sphalerite, and galena. This indicates beyond question that the same solutions that carried the tourmaline-producing elements carried also those of the metallic sulphides; it indicates further that, while conditions were locally unfavorable for the deposition of the sulphides in open fractures, they were favorable for their deposition in the adjoining wall rock. The veinlets, representing the conduits of the metalliferous solutions, were the loci of most intense thermal and chemical energy, and these places favored the deposition of the tourmaline. A partial segregation of the sulphides from the tourmaline was thus brought about.

In the Wickes district the ore bodies occur mainly in the intruded andesites. The Alta mine, whose output is by far the largest of any mine in the Helena region, is situated on Alta Mountain a few miles northwest of Wickes.

The production of the mine previous to 1893 is stated to have aggregated 1,250,000 tons of lead-silver ore yielding $32,000,000, and up to that time only the highest grade ore was shipped.[1]

The prevailing rock in the vicinity of the Alta mine is a latitic andesite. That at the summit of the mountain shows a pronounced streaky and flow-banded structure. The intrusive quartz monzonite occurs several hundred yards east of tunnel No. 8; on the wagon road below the mine a dike of coarse aplite and two dikes of dacite 50 or 100 feet wide are exposed penetrating the andesite.

The underground workings being inaccessible, only surface observations are available. These show that the ore body, trending slightly south of west, is enclosed in the andesites and that the ore minerals consist of galena, sphalerite, and pyrite. The introduction of the ore, as shown by material on the dumps at 6,100 feet altitude, was accompanied by intense tourmalinization, so that radial aggregates of black tourmaline are common in the altered andesite. In places the andesite was fractured and netted with quartz-tourmaline veinlets and impregnated with pyrite. Such rock examined microscopically proves to be composed of quartz and sericite in nearly equal abundance, tourmaline, and pyrite.

It will therefore be seen that here, as at Rimini, the product of complete metasomatic alteration is essentially a quartz-sericite rock, although in the one case the original rock was a eugranitic quartz monzonite, and in the other a porphyritic andesite.

CHEMICAL PROCESSES.

The chemical processes accompanying the formation of the tourmalinic silver-lead deposits were investigated by a series of analyses of rocks from the Valley Forge mine at Rimini.

The normal country rock, taken 30 feet in the foot-wall of the lode at the portal of the main tunnel, is a comparatively fresh quartz monzonite composed of zoned plagioclase near $Ab_{51}An_{49}$, orthoclase, quartz, micropegmatite, biotite, and hornblende, with

[1] "Mineral Resources U. S. for 1909," p. 374.

accessory magnetite, titanite, apatite, and zircon. Sericite, chlorite, and iron oxide occur in small amounts as secondary minerals. Altered quartz monzonite, taken from rock adjoining the quartz-tourmaline ledge on the hanging wall and selected so as to contain a minimum of tourmaline, is a coarse quartzose rock containing considerable glossy sericite in fine scales and pyrite in deeply striated cubes. Arsenopyrite, sphalerite, and galena are present in lesser quantities. Under the microscope quartz in large optically homogeneous anhedrons is seen to be the dominant constituent; sericite and sulphides are common. Tourmaline, a deep brown iron-rich variety is present in small amount. Arseno-

ANALYSES OF FRESH AND ALTERED WALL ROCKS.

	1	2	3	4
SiO_2	65.91	66.70	66.02	69.42
Al_2O_3	15.32	13.25	14.14	15.65
Fe_2O_3	2.28	1.34	1.53	1.25
FeO	2.02	.51	.37	3.30
MgO	1.52	.30	.67	1.02
CaO	3.28	.05	.26	.63
Na_2O	3.08	.39	.39	.27
K_2O	4.80	4.03	4.63	4.06
H_2O −	.60	.08	.10	.06
H_2O +	.60	.37	.48	.54
TiO_2	.59	.20	.56	trace
CO_2	.21	.21	.25	
P_2O_5	.18	.12	.17	.40
MnO	trace	trace	trace	.39
BaO	.10	none	.04	
Li_2O				.81
B_2O_3				.59
F			.02	3.36
PbS		.59	2.02	
ZnS		1.86	.74	
FeS_2		5.09	6.73	
FeAsS		4.75	.72	
				101.75
Less O for F				1.41
	100.51	99.84	99.84	100.34
Specific gravity	2.651		2.893	

1. Quartz monzonite, fresh. From Rimini, Mont. J. G. Fairchild, analyst.
2. Quartz monzonite, altered. From hanging wall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
3. Quartz monzonite, altered. From footwall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
4. Greisen (with tourmaline and topaz), St. Michael's Mountain, Cornwall. W. Pollard, analyst.

pyrite as a rule is sharply crystalline; pyrite is also well crystallized, but the galena and sphalerite are anhedral. Apatite and zircon appear as accessory minerals.

Rock taken from the footwall, and therefore several feet from the tourmalinic ledge, consists of highly sericitized quartz monzonite impregnated with pyrite, galena, arsenopyrite, and sphalerite. The sericite forms translucent waxy patches of light yellowish-green color. The microscope shows that the component minerals are, in order of abundance, quartz, sericite, pyrite, galena, arsenopyrite, sphalerite, and accessory rutile, apatite, and zircon.

It is apparent from these analyses that the course of alteration has been essentially similar in both wall rocks; noteworthy, however, is perhaps the fact that the high arsenopyrite and low galena go with the tourmaliniferous phase of alteration. The pronounced decrease amounting to nearly complete removal of all bases other than K_2O and the low combined H_2O—lower than in the unaltered rock—are striking features. The K_2O, as shown by the microscopic diagnosis, is all present in sericite, but the amount of H_2O is far too low to compute the sericite as $K_2O \cdot 2H_2O \cdot 3Al_2O_3 \cdot 6SiO_2$, the formula usually employed. In this respect the alteration of these wall rocks departs from that of most sericitized wall rocks, it being general experience that H_2O is commonly in excess of the amount required by the formula $K_2O \cdot 2H_2O \cdot 3Al_2O_3 \cdot 6SiO_2$. For purposes of comparison an analysis of a greisen from Cornwall has been added, which shows a similar deficiency of H_2O with regard to the content of potash.[1] But such examples are rare.

To trace the course of alteration more closely the following computations have been made, based upon the assumption of constant volume. They bring out clearly that the net increase of mass, amounting to 9 per cent., has been due chiefly to the introduction of the metallic sulphides; that there has been a notable gain in iron (as pyrite and arsenopyrite), sulphur, lead, arsenic,

[1] Reid, Clement, and Flett, J. S., "Geology of the Land's End District," Mem. Geol. Survey England and Wales, 1907, p. 59.

zinc, and silica; and that there has been a heavy loss in all bases except potash, which has remained practically unchanged in amount.

ALTERATION IN QUARTZ MONZONITE, RIMINI.

	1	2	1*a*	2*a*	3	4	5
SiO_2.....	65.91	66.02	174.80	191.00	+16.2	+ 9.28	+6.12
Al_2O_3.....	15.32	14.14	40.60	40.90	+ 0.3	+ 0.74	+ .10
Fe_2O_3.....	2.28	1.53	6.05	4.43	− 1.62	−26.8	− .61
FeO.....	2.02	.37	5.36	1.07	− 4.29	−80.1	−1.62
MgO.....	1.52	.67	4.03	1.94	− 2.09	−51.9	− .79
CaO.....	3.28	.26	8.70	.75	− 7.95	−90.4	−3.00
Na_2O.....	3.08	.39	8.17	1.13	− 7.04	−86.2	−2.65
K_2O.....	4.80	4.63	12.72	13.38	+ .66	+ 5.19	+ .20
H_2O −.....	.60	.10					
H_2O +.....	.60	.48	1.59	1.39	− .20		
TiO_2.....	.59	.56	1.56	1.62	+ .06		
CO_2.....	.21	.25	.56	.72	+ .16		
P_2O_5.....	.18	.17	.48	.49	+ .01		
BaO.....	.10	.04	.26	.12	− .14		
PbS.....		2.02		5.84			+2.20
ZnS.....		.74		2.14			+ .81
FeAsS.....		.72		2.08			+ .78
FeS_2.....		6.73		19.45			+7.33
	100.51	99.82	264.88	288.45			+8.87
Specific gravity...	2.651	2.893					

1. Chemical composition of unaltered quartz monzonite.
2. Chemical composition of altered quartz monzonite.
1*a*. Constituents in grams of 100 c.c. of unaltered rock.
2*a*. Constituents in grams of 100 c.c. of altered rock.
3. Gain or loss in grams of each constituent during alteration.
4. Gain or loss in percentage of original mass of each constituent.
5. Gain or loss in percentage of original mass of the unaltered rock.

SYSTEMATIC IMPORTANCE.

As is well known a sharp distinction was drawn by French geologists between the cassiterite-bearing veins and the ordinary sulphide-bearing veins—the so-called *filons plombifères*. This division into the two groups is recognized by Vogt[1] as valid—only that here, as elsewhere in nature, transitional forms exist. Certain such gradations are pointed out by him, but in conclusion

[1] "Genesis of Ore Deposits," special publication Am. Inst. Min. Eng., 1902, p. 665.

he states, "galena-silver ore veins carrying tourmaline in abundance are not known." A review by Stutzer in 1906 of all known tourmaline-bearing ore deposits confirms this statement.[1] Eight classes, the limits of which, however, are somewhat arbitrary owing to transitional forms, are defined: (1) Stanniferous, which are commonly tourmaliniferous; (2) tourmalinic copper; (3) tourmalinic cupriferous gold-quartz; (4) tourmalinic pyritic gold-quartz; (5) tourmalinic arsenical gold-quartz; (6) tourmalinic cobalt; (7) tourmalinic siderite; and (8) tourmalinic specularite-magnetite. These exhausted the list known at that time.[2] In 1907 L. J. Spencer[3] showed that tourmaline was abundantly associated with the tin and bismuth ores of Tasna, Bolivia, and later writers, namely Rumbold and Armas, have called attention to the widespread occurrence of tourmaline in the Bolivian ores. As Spencer points out, the supposed absence of tourmaline had been especially emphasized by Stelzner,[4] who regarded the Bolivian tin deposits as constituting marked exceptions to the rule that stanniferous deposits are commonly tourmaline-bearing. The notable silver content of these ores makes them of great genetic significance, placing them as it does in the category of a transitional type between the true stanniferous type and the galena-silver type—a feature accentuated by the recently acquired information concerning their tourmaliniferous character. Lately H. V. Winchell and A. N. Winchell have called attention to the tourmalinic copper-silver ore of the Blue Bird mine, near Wickes, in the Helena mining region.[5]

From this review of the known occurrence of tourmaline-bearing ore bodies, it will be seen that the deposits belonging to the pure

[1] Stutzer, O., "Turmalin führende Kobalterzgänge," *Zeitschr. f. prakt. Geologie*, Vol. 14, 1906, pp. 294–298.

[2] Tourmaline is recorded as occurring in the wall rock of a silver-lead mine at Tintic, Utah; the tourmalinization is not, however, specifically described as due to the action of the ore-depositing agencies (Tower, G. W., and Smith, G. O., 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 636).

[3] *Mineralogical Magazine*, Vol. 14, 1907, p. 336.

[4] Stelzner, A. W., "Die Silber-Zinnerzlagerstätten Bolivias," *Zeitschr. Deutsch. geol. Gesell.*, Vol. 49, 1897, pp. 51–142.

[5] "Notes on the Blue Bird Mine," Econ. Geol., Vol. 7, 1912, pp. 287–294.

type of tourmalinic lead-silver ores have not previously been described. It is therefore a matter of some theoretic interest to find a series of highly tourmalinic galena-silver lodes genetically related to the intrusion of the Boulder batholith. Tourmaline is the most characteristic mineral of the stanniferous deposits; here in Montana it is developed in extreme abundance as an accompaniment of silver-lead deposits. The lodes, moreover, have been important producers: of these the largest, the Alta, credited with a yield of $32,000,000, appears, if the stanniferous lodes are excluded, to outrank in value of output any known ore body of the tourmalinic class of deposits.

THE DETERMINATION OF THE RELATIVE VOLUMES OF THE COMPONENTS OF ROCKS BY MENSURATION METHODS.

FRANCIS CHURCH LINCOLN AND HENRY LEWIS RIETZ.

I. GENERAL CONSIDERATIONS.

A determination of the relative volumes of the components of a rock may have for its object description, nomenclature, computation of chemical composition, estimation of desirable or undesirable mineral content, or comparison. A quantitative statement of the mineralogical composition of a rock is essential to a good description. While the mineralogical classification of rocks is not on a strictly quantitative basis, yet some estimate of the relative proportions of components, if only a rough one, is necessary before a rock can be named. Chemical nomenclature and chemical composition may be more directly obtained from chemical analysis. The commercial importance of determining directly the proportion of a valuable or harmful mineral is self-evident; and comparisons of mineral compositions of rocks may also have considerable economic value.

This is especially true in metal mining and in quarrying stone. Owing to the intimate relationship frequently existing between ore deposits and country rocks, a mineralogical comparison of the rocks in a mining district is frequently of value. A good example of a comparative study of this nature is presented by Barrell in his "Microscopical Petrography of the Elkhorn Mining District, Jefferson County, Montana."[1] The relative quantities of the components of building and ornamental stones affect their properties and render comparative studies desirable. A good example of such a study is Dale's "The Chief Commercial Granites of Massachusetts, New Hampshire and Rhode Island."[2]

[1] 22nd Ann. Rep. U. S. Geol. Sur., Part II. (1901), 511–549.
[2] U. S. Geol. Sur. Bull. 354 (1908).

In the two works just cited, methods dependent on measurements were employed to determine the relative amounts of the components of the rocks. Such methods may well be termed "mensuration" methods; and other methods which might have been used and are dependent on chemical analyses and specific gravity manipulations may be called "chemical" and "density" methods respectively. These latter methods may be subdivided into "simple" and "complex," according as they require a single analysis or manipulation, or several; while the former methods may be subdivided into "areal" and "linear" according as they call for the measurement of areas or of lines. The proposed classification is as follows:

Mensuration: { Simple, Complex.

Density: { Simple, Complex.

Chemical: { Areal, Linear.

Before taking up the details of the mensuration methods, it seems advisable to outline briefly and to compare all methods. The chemical methods destroy the mineral components by solution at the outset and never afterward deal with them directly; the density methods deal with the components in volumes; and the mensuration methods deal with them in areas or in intercepts.

The simple chemical method consists in making a chemical analysis of the rock and computing the chemical constitutents to mineral components. This method is not only indirect, but it also calls for expert chemical manipulation. There are four cases in which it cannot be applied: (1) when two minerals of the same composition occur in the rock, (2) when two minerals are present whose combination in any proportion might produce a third mineral which also exists in the rock, (3) when minerals whose composition is variable are involved, and (4) when a mineral of unknown composition is a component. In the first

two cases, the chemical methods fail completely, but in the last two the complex chemical method may be employed.

The complex chemical method consists in obtaining an analysis of the rock as in the simple method and supplementing it by analyses of the variable or unknown minerals present. It is open to the same objections as the simple method and has the additional disadvantages that it is difficult to separate the rock constituents to obtain the material for the supplementary analyses, and that it consumes a very considerable amount of time. It should be noted that a very close approximation can be made in the case of variable minerals without resort to the complex method, since it has been shown that variable minerals have similar compositions in similar rocks. Published analyses of variable minerals in similar rocks may thus be substituted in place of actual analyses without occasioning large errors.

The simple density method consists in computing the mineral components of a rock from a specific gravity determination. It is only applicable to rocks consisting of two minerals of different specific gravities. It is simple, direct and extremely rapid, but since most rocks contain more than two minerals its application is very limited.

The complex density method is more widely applicable. It consists in crushing a sample of rock, separating the fragments into groups according to specific gravities by means of heavy solutions, and computing the relative proportions of components from the amount in each group. Although a direct method, the objections to this procedure are much more serious than those to the indirect chemical methods. No matter to what degree of fineness the crushing is carried, it never completely detaches the mineral particles from one another. Even if equal quantities of minerals clung to each other, as might happen in rare instances, the results would be invalidated in the case of a rock consisting of more than two minerals,—the only rock requiring the complex process,— because particles of minerals of higher and lower densities when attached to one another would sink in a heavy solution with pure grains of intermediate density. Fine crush-

ing reduces this error but introduces another by producing a quantity of dust so fine that it will not settle in water,—much less in heavy solutions. This material is only proportional to the minerals present in those rare instances when all of these minerals are of the same degree of brittleness. In most cases, it contains a higher proportion of the more brittle minerals in the rock than does the coarser portion, and its removal before the heavy solution treatment vitiates the results. It is apparent that this method calls for considerable manipulative skill. It fails completely when minerals of the same specific gravity occur in the rock.

In the mensuration methods, the areas or intercepts of the mineral components, recognized by their optical properties, are estimated or measured directly, and the percentages computed from their sums. The mensuration methods have the advantage over the chemical methods that they are less liable to error since they measure the rock components directly; over the simple density method that they have a more general application; and over the complex density method that they are more reliable since free from its innate limitations. Over both chemical and density methods they have two obvious advantages—they require no expert manipulation other than petrographical, and the samples employed remain intact for future reference and study.

II. DESCRIPTION OF MENSURATION METHODS.

The estimation of the proportions of minerals in a rock by the examination of specimens or exposures is dependent upon mental measurements of the comparative areas of the minerals viewed and is properly an areal mensuration method. This is the commonest of all mensuration methods and was undoubtedly the first to be employed.

A real estimation may also be used in microscopy. Barrell describes the procedure in the following words:

"The field of the microscope is divided into quadrants by the cross hairs, and these are mentally divided into sectors which are thirds, fifths or smaller fractions. By taking such a power of objective that the component to be estimated is represented in the field of view by a fair num-

ber of crystals, the latter can be mentally collected together and packed in one quadrant, and the fraction which it fills estimated."[1]

The first mensuration method to make use of physical measurements was the areal method of Delesse.[2] He applied a transparent sheet of paper or goldbeaters' skin to the polished or nearly plane surface of a rock and traced upon it the outlines of the various mineral grains. The sketch was then tinted so that the various minerals might be distinguished, and the sheet pasted with soluble gum to a piece of tin foil. The variously tinted surfaces with their adhering tin foil were next cut apart and grouped according to their colors, the paper washed away, the tin foil particles in each group weighed, and the percentages of the various mineral components of the rock computed directly from these weights.

Sorby[3] extended this method to microscopy, and at the same time eliminated the complicated tin foil procedure into which Delesse had been forced on account of the character of the paper he employed. Sorby says:

"In order to know the relative bulk of the constituents, whether organic or mineral, I select a portion of the object that shows the general character in a satisfactory manner, and draw on an evenly thick piece of drawing-paper the outline of the various portions with a camera lucida, distinguishing by some mark the different constituents. I then weigh the whole in accurate balances and afterwards cut out the various portions and weigh them."

Julien[4] used microphotographs, cutting them up and weighing the fragments just as Sorby did his camera lucida sketches.

Williams[5] measured the areas of the grains directly by means of an eyepiece micrometer cross-ruled into squares. The squares which came within the boundaries of each particle were counted, and from the measurements obtained the relative volumes of the various minerals were computed.

[1] *Op. cit.*, p. 513.
[2] *Comptes Rendus, 25* (1847), 544–545.
[3] *Philosophical Mag., 11* (1856), 21.
[4] *Bull. Geol. Soc. of Am., 14* (1903), 466.
[5] *Am. Geol., 35* (1905), 44.

Lincoln has found the measurement of areas with a planimeter very satisfactory. The planimeter may be used upon a camera lucida drawing, a photograph, an illustration, or directly upon the surface of a coarse-grained rock. As in Williams' method, the areas are obtained without recourse to weighing, thus eliminating one source of error and saving time, while the use of the planimeter is far less trying to the eyes than that of the cross-ruled micrometer. Furthermore, the planimeter method has the advantage that it may be used upon a valuable sketch or photograph or upon a figure in a book without injury to the subject.

The linear mensuration method was devised by Rosiwal.[1] It consists in measuring the intercepted lengths of grains along a line or series of lines and calculating the percentages by volume by dividing the total distance measured into the sum of the intercepts for each component. As Rosiwal expresses it:

> "In place of Delesse's leaf of rock we have a thread of rock, an exceptionally slender prism whose volume is comparable to the extremely slender core of a borehole of the smallest possible dimensions."

If the mineral particles are of large size, the intercepts may be measured directly upon a smooth face with the aid of a pair of dividers and a scale. The measurements may follow a ruled line or an imaginary one. A convenient method in the case of a small specimen is to stretch an elastic about it and to measure the intercepts along the upper edge of the rubber band. In this way, none of the minerals are obscured, and if it happens that a grain barely extends beyond the elastic, the band may be temporarily pushed aside while the mineral is being identified.

When the linear method is used microscopically, thin lines are ruled in ink across the cover glass of the thin section. Such lines are semi-transparent, and if they do interfere with the identification of a mineral at any point, may be readily erased at that spot. The measurements along these lines are conveniently made with an eyepiece micrometer.

[1] *Verh. der k. k. geol. Reichsanstalt* (1898), 143–175.

III. THEORY.

Delesse[1] outlined a proof by calculus that the sums of the areas of the components on a plane surface of a rock are proportional to the volumes of the components in the rock. Rosiwal[2] extended this form of proof to show that intercepts on lines are also proportional to volumes. Despite these proofs, Julien[3] and Williams[4] hold that the results obtained by mensuration methods are not directly proportional to volumes, but rather to diameters or squares of diameters, and that the shapes of the individual mineral grains play an important part and must be taken into consideration in the calculations. Since the theory of the mensuration methods has thus been called into question, the following alternate geometrical proof is presented.

According to Cavalieri's theorem, "Two solids lying between two parallel planes, and such that the two sections made by any plane parallel to the given planes are equal, are themselves equal."[5] Then two solids lying between two parallel planes, and such that the two sections made by any plane parallel to the given planes have a constant ratio, have themselves that same ratio. For if the ratio were $a:b$, then the first solid might be formed from a equal Cavalieri bodies and the second solid from b of the same solids, when the ratio of the volumes of the solids would be $a:b$. Furthermore, two groups of solids lying between two parallel planes, and such that the sums of the sections of the two groups made by any plane parallel to the given planes have a constant ratio, have themselves that same ratio. For these groups might be formed by cutting up the solids previously considered, and moving the fragments parallel to the given planes, when the ratios would not be disturbed. Finally, since any number of groups may be considered two at a time, (*I.*) *Groups of solids lying between two parallel planes, and such that the sums of the sections of the groups made by any plane parallel to the given planes have a constant ratio, have themselves that same ratio.*

[1] *Annales des Mines*, Series IV., *13* (1848), 380–383.
[2] *Op. cit.*, pp. 146–147.
[3] *Bull. Geol. Soc. of Am.*, *14* (1903), 460.
[4] *Am. Geol.*, *35* (1905), 40–46.
[5] Beman and Smith, "New Plane and Solid Geometry" (1900), 358.

Stated for plane surfaces, this becomes: (*II.*) *Groups of plane areas lying between two parallel lines, and such that the sums of the intercepts of the groups made by any line parallel to the given lines have a constant ratio, have themselves that same ratio.*

Now let us consider the case of a rock composed of mineral particles thoroughly mixed so that the laws of chance come into play. If a number of parallel lines are drawn in any plane in this rock, they will intercept grains of the different minerals in ratios which will show less fluctuation the longer the lines. By taking a sufficient length for these lines, the ratios may be made constant to any desired degree of accuracy. It follows from proposition *II.*, that in the case of a rock composed of well-mixed grains, the sums of the intersected lengths of mineral particles along a sufficiently protracted line are proportional to their areas.

Let us next consider a number of parallel planes passed through this same rock. They will make sections of the different sorts of mineral grains the ratios of whose sums will vary less the greater the areas of the planes. If these planes are taken large enough so that these fluctuations become negligible, then from proposition *I.*, the sums of the sections of the mineral particles will be proportional to their volumes.

Finally, it follows that if a plane is taken of sufficient extent so that any line in it will intercept lengths of minerals proportional to areas of sections, such plane will also make sections of minerals proportional to their volumes, and thus the sums of intercepted lengths will be proportional not only to areas but also to volumes.

IV. REQUISITE NUMBER OF MEASUREMENTS.

A. Statement of Rosiwal.—Having assured ourselves that the theory of the mensuration methods is sound, we naturally inquire next as to the number of mineral particles to be measured in order reasonably to expect a desired degree of accuracy in the derived precentage of the volume. In discussing this question of accuracy, we shall confine ourselves to the linear mensuration method of Rosiwal because it is the simplest method and the one most readily applied.

Rosiwal says:

"It is easily seen that the degree of accuracy must be directly proportional to the length of the indicatrice selected for measurement and inversely proportional to the size of the grains of the rock. Under the assumption of greatest possible regularity of distribution and size of grains of the component minerals of the rock, we must select a length of indicatrice equal to at least one hundred times the size of the grains to obtain an accuracy of measurement of approximately 1 per cent.; and, with not unexceptionable regularity of distribution, must surely measure several indicatrices lying in different planes of a parallelopiped (cube)."[1]

That 100 measurements is insufficient under ordinary conditions to lead us reasonably to expect an accuracy of 1 per cent., is clear from Rosiwal's own sketch and measurements of a quartz-biotite-diorite from Pozar, Bohemia.[2] We estimate that 204 intercepts were measured in one direction upon this specimen and 215 intercepts in a direction at right angles to this. The percentages of quartz, feldspar, and biotite computed from these two sets of measurements deviate by 1.5 per cent., 3.6 per cent., and 1.6 per cent. respectively. Moreover, by thus measuring across the same surface in two directions, the full effect of random sampling can hardly be attained, and results so secured may reasonably be expected to show smaller deviations than would have been obtained by the measurement of two distinct random samples of the same rock.

Rosiwal's minimal requirement does not, therefore, give us even a general idea as to the number of grains that should be measured to secure a desired degree of accuracy, and his valuable article contains no other statements which have a direct bearing on this point.

B. Algebraic Formulation of the Problem.—Two kinds of errors may enter into this problem—those due to incorrect measurements and those due to chance fluctuations in the material measured. The first class of errors is of but slight importance in the present problem and will not be specially considered. The

[1] *Op. cit.*, p. 148.
[2] *Ibid.*, pp. 159 and 161.

second class of errors is due to the element of chance introduced when we consider the grains of a mineral which will be intercepted by a random line run through a rock, and is of prime importance in our problem.

Let us assume that the mineral particles in a rock are so thoroughly mixed that the laws of chance come into play. We may then depend upon a random sample for the determination of the percentages of the various components, and any subsequent determination from a similar random sample will manifest fluctuations whose character will be in conformance with the laws of random sampling. The problem is to determine approximately the number of grains, n, whose intercepts should be measured so that, under the theory of random sampling, we may reasonably expect that the error in the ratio, p, of the volume of a certain mineral, A, to the total volume of the rock shall not exceed a certain percentage, E. Let the individual intercepts of A be x_1, x_2, . . . x_n and the arithmetical mean of these intercepts be $\bar{x}$. Also let σ_x be the standard deviation of these intercepts, that is, the square root of the arithmetical mean of the squares of the deviations of the individual intercepts from their arithmetical mean. Then

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n} \tag{1}$$

and

$$\sigma_x = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \cdots + (x_n - \bar{x})^2}{n}}. \tag{2}$$

Now let $y_1, y_2, \ldots, y_n$ be the intercepts of the spaces between the grains of A, $\bar{y}$ their arithmetical mean, and σ_y their standard deviation. Then

$$\bar{y} = \frac{y_1 + y_2 + \cdots + y_n}{n} \tag{3}$$

and

$$\sigma_y = \sqrt{\frac{(y_1 - \bar{y})^2 + (y_2 - \bar{y})^2 + \cdots + (y_n - \bar{y})^2}{n}} \tag{4}$$

and

$$p = \frac{n\bar{x}}{n\bar{x} + n\bar{y}} = \frac{\bar{x}}{\bar{x} + \bar{y}}. \tag{5}$$

Next let δp be the change from the most probable value of p to be expected in taking samples. Then

$$\delta p = \frac{\bar{y}\delta\bar{x} - \bar{x}\delta\bar{y}}{(\bar{x} + \bar{y})^2} \tag{6}$$

and

$$\overline{\delta p^2} = \frac{\bar{y}^2(\delta\bar{x})^2 + \bar{x}^2(\delta\bar{y})^2 - 2\bar{x}\bar{y}\delta\bar{x}\delta\bar{y}}{(\bar{x} + \bar{y})^4}. \tag{7}$$

Summing up the δp^2's for the different samples and dividing by the number of samples, the square of the standard deviation of p is obtained. Let σ_p be the standard deviation of p. Then, if x and y are uncorrelated, we have by summation of (7), to correspond to any number of repetitions:

$$\sigma_p^2 = \frac{\bar{y}^2\sigma_{\bar{x}}^2 + \bar{x}^2\sigma_{\bar{y}}^2}{(\bar{x} + \bar{y})^4}. \tag{8}$$

And since $\sigma_{\bar{x}}^2 = \sigma_x^2/n$, and $\sigma_{\bar{y}}^2 = \sigma_y^2/n$

$$\sigma_p^2 = \frac{\bar{y}^2\sigma_x^2 + \bar{x}^2\sigma_{\bar{y}}^2}{n(\bar{x} + \bar{y})^4} \tag{9}$$

and

$$n = \frac{\bar{y}^2\sigma_x^2 + \bar{x}^2\sigma_y^2}{\sigma_p^2(\bar{x} + \bar{y})^4}. \tag{10}$$

The probable error in a determination is an amount such that there is an even chance that if a similar determination be made from a second random sample it will deviate from the first by more or by less than that amount. The probable error of a single determination is 0.6745 times its standard deviation. So the probable error of p is $0.6745\sigma_p$ (11).

If we are willing that a determination of p shall have a probable error of 1 per cent., then we shall have

$$0.6745\sigma_p = 0.01,$$

$$\sigma_p = 0.01482,$$

and with $\sigma_p = 0.01482$, (10) becomes:

$$n = 4550 \frac{\bar{y}\sigma_x^2 + \bar{x}\sigma_y^2}{(\bar{x} + \bar{y})^4} \text{ (approximately).} \qquad (12)$$

The employment of the probable error in this manner ensures only an even chance that a second similar determination will check within E per cent. If twice the probable error be used in obtaining a formula for n, the chances are 4.5 to 1 that a second determination will not vary by more than E per cent.; if three times, the chances are 21 to 1; and if 4 times, 142 to 1. We may therefore feel reasonably sure that the deviation will not exceed E per cent. if we make use of 3 or 4 times the probable error in deducing our formula. Now in obtaining the formula for n the probable error is squared, so to obtain such a value for n that we may reasonably expect a second determination of p to check within 1 per cent. we must multiply (12) by some number from 9 to 16, or say at least 10, giving

$$n = 45{,}500 \frac{\bar{y}\sigma_x^2 + \bar{x}\sigma_y^2}{(\bar{x} + \bar{y})^4}. \qquad (13)$$

C. Solution of Problem for a Maine Granite by Intercept Method.—In order to form a definite idea of the number required in an actual case, we measured the intercepts along ten parallel lines on a polished specimen of biotite-granite from Maine. The components of this rock are glassy quartz, pink orthoclase, milky white oligoclase, and black biotite, fairly well mixed but showing some tendency to segregation. The intercepts were measured macroscopically with a pair of dividers and a scale ruled in hundredths of an inch.

The frequency distributions of the measurements of intercepts of grains and of spaces between grains for each mineral are presented in Table I. There also will be found the arithmetical means and standard deviations calculated by the short and accurate method of Davenport and Rietz.[1] A study of the correlation of x's and y's for quartz shows that correlation is absent, even between successive x's and y's, and thus makes it certain

[1] Bull. Agric. Exp. Sta. Univ. of Ill., *119* (1909), 9–11.

TABLE I.

Frequency Distributions of Measurements of Maine Granite.

Length in Hundredths of an Inch.	Number of Measurements.							
	On Grains of:				On Spaces between:			
	Quartz.	Orthoclase.	Oligoclase.	Biotite.	Quartz.	Orthoclase.	Oligoclase.	Biotite.
0					74	5	1	0
1	77	76	56	59	54	53	7	8
2	89	65	37	23	43	59	17	3
3	61	48	29	13	31	37	6	2
4	55	24	21	6	27	25	11	1
5	47	24	10	2	26	19	11	1
6	23	22	7	—	18	21	3	2
7	24	16	9		14	19	9	0
8	13	15	5		10	18	4	2
9	7	7	3		10	14	3	4
10	2	8	0		11	15	5	1
11	0	9	1		9	10	4	1
12	0	5	0		4	6	4	2
13	1	5	1		5	6	4	2
14	—	2	3		9	3	5	2
15		4	—		8	7	8	2
16		3			4	6	6	4
17		2			3	4	4	2
18		4			6	5	6	1
19		1			5	1	4	1
20		2			5	1	5	5
21		1			3	1	1	2
22		2			2	2	4	3
23		0			3	1	0	3
24		0			0	1	2	2
25		1			3	0	2	2
26		—			1	0	3	2
27					3	1	1	0
28					2	1	0	2
29					0	0	1	2
30					0	0	2	0
31					2	1	3	0
32					1	1	3	1
33					0	1	1	0
34					0	0	1	2
35					0	0	3	0
36					0	0	0	1
37					0	0	1	1
38					0	0	0	1
39					0	0	0	1
40					0	0	2	1
41					0	0	1	1
42					0	0	2	0
43					0	0	0	0
44					0	0	3	1
45					0	1	2	0
Various lengths above 45					(2, the highest being 68)	—	(13, the highest being 88)	(29, the highest being 141)
Arithmetical mean.....	3.506	4.88	3.236	1.733	5.910	6.16	18.05	29.5
Standard deviation.....	2.241	4.54	2.651	1.018	6.830	5.742	17.86	31.19

that the condition of no correlation between x and y called for by our algebraic formula is fulfilled. We may now substitute in (12) the values of x, y, σ_x, and σ_y for each mineral in turn and by solving the equations find the number of intercepts to be measured in each case for a probable error of 1 per cent. The results are shown in Table II.

TABLE II.

NUMBER OF INTERCEPTS OF MAINE GRANITE FOR A PROBABLE ERROR OF ONE PER CENT.

Mineral.	Percentage in Round Numbers.	Number.
Quartz	40	435
Orthoclase	40	480
Oligoclase	15	125
Biotite	5	17

To be reasonably certain that the error shall not exceed 1 per cent., it will be necessary to employ (13), securing results ten times those given in Table II.

The intercepts along ten parallel lines on each of two other specimens of the same granite were measured, and the arithmetical means and standard deviations of each mineral calculated. The probable errors in the mean intercepts for the new rocks and for the old rock were calculated, the probable error in a mean being 0.6745 multiplied by the standard deviation and divided by the square root of the number of measurements. By this method, the results shown in Table III. were obtained.

TABLE III.

MEANS AND STANDARD DEVIATIONS OF INTERCEPTS OF THREE SPECIMENS OF THE SAME GRANITE.

		Rock I.	Rock II.	Rock III.
Quartz:	Mean intercept	3.51	3.77	2.99
	Probable error in same	0.076	0.076	0.064
	Standard deviation	2.241	2.807	2.155
Orthoclase:	Mean intercept	4.87	5.16	4.39
	Probable error in same	0.16	0.17	0.17
	Standard deviation	4.54	5.30	4.60
Oligoclase:	Mean intercept	3.24	2.56	2.52
	Probable error in same	0.14	0.10	0.10
	Standard deviation	2.65	2.46	2.22
Biotite:	Mean intercept	1.73	1.52	1.50
	Probable error in same	0.068	0.038	0.057
	Standard deviation	1.02	0.717	0.825

The results are seen to be fairly concordant. They indicate that the rock is well mixed on the whole, the slight tendency to segregation of minerals observed being unimportant since all the variations obtained may be attributed to fluctuations in random sampling with the possible exception of the quartz in Rock III. and the oligoclase in Rock I. whose wider deviations may be in part due to segregation. We may therefore look upon the numbers in Table II. as fairly safe guides to the number of measurements required by rocks of this character.

D. Subsample Method.—The measurements of intercepts on each of the ten lines on each of the three rocks were kept separate, and the percentages of the various minerals for each line have been calculated and are exhibited in Table IV. Each sample has thus been divided into 10 subsamples which may be used to estimate roughly the probable error in the percentage based on the entire sample, by computing the probable error in the mean of the percentages in a similar way to that in which the probable errors in the means of intercepts were obtained for Table III.

Let us illustrate by a single instance, the quartz in Rock II. The standard deviation of the 10 subgroups in the table is 5.3. The probable error in the percentage based on these subgroups will therefore be $5.3(0.6745)/\sqrt{10} = 1.1$. So p is put down in the table as 41.71 ± 1.1. The other p's shown in the table were derived in like manner.

Next let us consider how many measurements should be taken to reduce to the desired error the probable error so found. As an example, let us take the quartz in Rock III., which has a probable error of 1.3 per cent. from 557 measurements and determine how many measurements we should expect to have to take to obtain a probable error of 1 per cent. The probable error in a mean is inversely proportional to the square root of the number of variates. Squaring, the number becomes: $(1.3/1.0)^2 = 1.69$. We must therefore take 1.69 times 557,—or 941 measurements,—in order to expect the probable error to be reduced to 1 per cent.

The method of using 10 subsamples to estimate the probable error in the percentages in the sample is far from an ideal method,

TABLE IV.

PERCENTAGES OF MINERALS IN SUB-SAMPLES.

Rock.	Line.	Quartz.		Orthoclase.		Oligoclase.		Biotite.	
		Intercepts.	Per Cent.	Intercepts.	Per Cent.	Intercepts.	Per Cent.	Intercepts.	Per Cent.
I.	1	37	34.3	38	45.5	21	17.0	6	3.2
	2	44	37.7	36	45.0	16	12.8	12	4.7
	3	36	35.4	37	50.8	11	7.8	14	6.0
	4	45	41.2	36	41.2	14	13.3	7	4.3
	5	34	32.8	34	42.4	19	20.0	11	4.8
	6	49	42.8	32	32.6	24	20.4	12	4.2
	7	40	32.4	31	46.0	19	15.4	12	6.2
	8	41	37.7	36	43.7	14	13.3	13	5.3
	9	37	37.1	23	38.7	26	22.1	5	2.1
	10	36	31.0	43	51.3	19	12.4	11	5.3
Total...	.....	399		346		182		103	
	P	36.3 ± 1.0		43.7 ± 1.2		15.29 ± 0.89		4.62 ± 0.25	
II.	1	54	35.1	50	51.1	21	9.1	15	4.7
	2	63	38.2	51	44.7	32	13.6	13	3.5
	3	58	43.2	34	35.5	32	16.8	19	4.5
	4	50	38.1	44	45.1	23	12.1	18	4.7
	5	70	45.5	43	38.0	36	11.5	21	5.0
	6	55	49.8	36	38.1	21	7.8	13	4.3
	7	71	43.9	50	38.0	24	13.5	18	4.6
	8	78	39.2	57	44.9	24	12.0	10	3.9
	9	52	37.7	40	47.2	25	10.0	21	5.1
	10	68	45.6	48	36.2	27	15.1	12	3.1
Total...	.....	619		453		265		160	
	P	41.71 ± 1.1		41.82 ± 1.1		12.13 ± 0.57		4.35 ± 0.17	
III.	1	59	45.9	39	40.4	18	9.2	10	4.5
	2	65	44.7	46	45.0	10	8.1	7	2.2
	3	58	45.7	37	36.7	23	13.6	10	4.0
	4	69	49.1	34	30.2	28	18.1	7	2.6
	5	42	37.8	27	42.1	19	16.7	9	3.4
	6	70	57.2	32	27.2	19	12.1	7	3.5
	7	47	44.7	27	35.8	20	15.3	10	4.2
	8	48	38.7	31	40.6	20	15.9	10	4.8
	9	55	35.3	30	42.3	34	16.6	18	5.8
	10	44	38.4	28	39.4	26	18.6	10	3.6
Total...	.....	557		331		217		98	
	P	43.7 ± 1.3		38.0 ± 1.2		14.45 ± 0.71		3.86 ± 0.21	

since with small numbers and but little knowledge of the actual distribution, the probable errors thus obtained have themselves a considerable probable error. It is therefore interesting to com-

pare the results obtained on Rock I. by this method with those obtained on the same rock by the intercept method.

TABLE V.

PROBABLE ERROR IN PERCENTAGES BY TWO METHODS.

Mineral.	Subsample Method.	Intercept Method.
Quartz	0.79	1.04
Orthoclase	1.2	1.2
Oligoclase	0.89	0.83
Biotite	0.25	0.40

It will be observed that both quartz and biotite give considerably larger probable errors by the more refined method based on the measurements of the individual intercepts than they do by that based on the measurements of subsamples. Nevertheless, the results obtained by the subsample method are near enough to those obtained by the intercept method to constitute an important indication as to the probable degree of accuracy attained.

V. SUGGESTED PROCEDURE.

It seems unlikely that the results obtained from the measurements of intercepts of one type of rock afford more than a general guide to what may be expected from some other type of rock. For rocks of a different type from that which we measured the following procedure is recommended.

It is desired to determine p with a reasonable certainty that it is correct within E per cent. Keep the measurements of intercepts in subgroups and by testing from time to time as described in section IV, *D.*, ascertain when sufficient measurements have been made to predict a probable error of E per cent. in the most variable mineral. Then make a frequency distribution similar to that shown in Table I. and determine whether the expected probable error has been obtained. If not, continue the measurement of intercepts until a probable error of E per cent. has been secured. Compute the percentages of the various minerals indicated by these measurements.

Measure a like number of intercepts, omitting the division into

subsamples and the making of a frequency distribution. Calculate the percentages suggested by this set of measurements There is an even chance that the most variable of these results will agree with the corresponding result in the first set of measurements within E per cent., so in the long run more than half of the percentages will check at this point. Average the percentages of those minerals which check and do not measure any more intercepts to those minerals.

Make the third series of measurements on intercepts of minerals which have not checked, keeping account of the total lengths of lines in which these intercepts are included. Continue this process until all the minerals in the rock have checked within E per cent.

Considerable time may be saved if it be permitted that one mineral be determined by difference. As the error in the mineral so determined will be but slightly greater than that in the minerals determined by checking, we recommend this variation of the method for general use. This means that in making the first set of measurements enough should be taken so that the *second* most variable mineral shall have a probable error of E per cent., and that in succeeding series the measurement of intercepts of the most variable mineral may be neglected.

If this procedure had been followed in the case of the three specimens of biotite-granite from Maine, with the requirement that E equal 1 per cent., the orthoclase would have been neglected after the first series of measurements and determined by difference at the end. The biotite in the first and second rocks would have checked within 1 per cent. In the third set of measurements, the oligoclase would have checked with that in the first. If measurements of a fourth sample were taken, they would be very likely to check the quartz. Even if that occurred, the chances would have been less favorable in this instance than might be expected in half of a large number of similar cases.

VI. TIME REQUIRED FOR A DETERMINATION.

It is impossible to state exactly the time that will be required for a determination of given accuracy by the linear mensuration method since it depends upon chance. We may, however, obtain a very rough idea of the amount of time required by considering the rather unfavorable case of the Maine granite discussed in the last paragraph of the preceding section.

If the suggested procedure had been followed in the case of this rock and the quartz had checked in the fourth sample, 3,283 intercepts would have been measured. At the rate of 5 measurements per minute, a rate that can be readily attained either macroscopically or microscopically, it would take 11 working hours to complete these measurements. It is hardly necessary to point out that these hours should not be taken consecutively on account of the great strain on the eyes even when making measurements with the naked eye. The calculations will consume about 2 hours, bringing the total up to 13, and if it is desired to check the orthoclase an additional 3 hours will be needed, making 16 hours in all, or say 2 working days of 8 hours each.

This may seem a long time to spend on a single determination of the relative volumes of the minerals in a rock, but with a rock of this type, even under the most favorable circumstances, we could not shorten the time to less than 1 day of 8 hours, while under the most unfavorable conditions the time might have to be extended to 8 days of 8 hours. Fortunately, however, more than half of any large number of determinations on rocks of this character would require less than 2 days of 8 hours.

When we consider that a chemical analysis of a rock calls for 5 days of 8 or 10 hours,[1] the time required for a linear determination does not seem so excessive. It is well to note in passing that while duplicate chemical analyses on the same sample may check with a high degree of accuracy, it does not follow that a second random sample of the same rock would give results in close agreement with the first. This depends upon whether a sufficiently

[1] H. S. Washington, "Manual of the Chemical Analysis of Rocks" (1904) 69–70.

large original sample was taken and upon whether it was crushed to a sufficient degree of fineness before each reduction in size of sample. The easiest way to determine whether these conditions have been fulfilled is to take a second sample of similar size, reduce it in a similar manner, analyze it and decide from the deviations of the different constituents whether the sampling has been properly done. Such a procedure would practically double the time required for a chemical determination and make the time required for a linear determination seem short in comparison.

VII. SUMMARY.

The mensuration methods are simple and direct and it has been shown that they are theoretically sound. The linear mensuration method is readily applicable both macroscopically and microscopically and has been studied in detail. Two methods of determining its degree of accuracy have been presented and a systematic procedure for making a determination has been outlined. It has been shown that the time required to determine the components of a granite rock to within 1 per cent. of the rock for each component will ordinarily require less than two days.

The linear mensuration method is therefore recommended for general use in the determination of the relative volumes or relative weights of the components of a rock.

METALLIC MINERALS AS PRECIPITANTS OF SILVER AND GOLD.[1]

CHASE PALMER AND EDSON S. BASTIN.

INTRODUCTION.

In the progress of certain experiments in the chemistry of secondary enrichment the writers were interested to note the great efficacy of certain metallic minerals, notably chalcocite and niccolite, as precipitants of metallic silver and gold. If a piece of chalcocite is hung in a dilute aqueous solution of silver sulphate (1/40 normal) a coating of silver begins to form immediately on the mineral and in a short time a beautiful silver tree has developed similar to that formed when metallic zinc is immersed in a silver solution. The efficacy of chalcocite as a precipitant of gold is strikingly shown if a little of the mineral is finely powdered, placed in a test-tube and two or three cubic centimeters of a dilute solution of gold chloride poured upon it. Two or three shakes of the tube suffice to remove all the gold from the solution. The color of the latter changes from yellow to green, showing that copper is dissolved simultaneously with the precipitation of metallic gold.

The experiments were extended to include a considerable number of sulphides, arsenides, etc., especially those known to be commonly associated with the precious metals in nature. They reveal great differences in the efficiency of minerals as precipitants, especially in their action on silver solutions. Detailed quantitative studies were also made of the reaction of silver sulphate solution with chalcocite and niccolite so that it is possible to write the correct formulae for the reactions. Further quantitative studies are now in progress with other minerals in the laboratory

[1] Published with the permission of the Director of the U. S. Geological Survey.

of the U. S. Geological Survey but as the phenomena under discussion appear to have an important application in the study of ore deposits, particularly in secondary enrichment, it has seemed best in this preliminary paper to outline the field of investigation and thus make the main results immediately available to economic geologists.

The literature bearing directly or indirectly on the precipitation of the precious metals by sulphides is widely scattered and for this reason is summarized below. The earliest important work on this subject by W. Skey[1] published in 1871 in a New Zealand publication appears to have wholly escaped the attention of economic geologists until very recently. Skey's work, however, blocked out one of the most interesting and promising fields of research in the province of ore deposits.

LITERATURE.

The earliest article of note which deals with the precipitation of precious metals by metallic minerals was written by C. Wilkinson and appeared in 1867.[2] In this Wilkinson reports certain experiments in which he obtained a deposit of gold on pyrite, galena, chalcopyrite, arsenopyrite, stibnite, molybdenite, sphalerite and wolframite when these were immersed, *together with a piece of wood or leather,* in a solution of $AuCl_3$. When the experiments were repeated with most of these without organic matter being present, no precipitate was obtained. Wilkinson concludes that

> "organic matter is the necessary chemical agent to decompose a solution of the chloride of gold in order to precipitate the gold as a coherent coating around a nucleus presented to it."

In 1870 W. Skey, who was familiar with Wilkinson's results, repeated these experiments. He took care to exclude all organic

[1] W. Skey, "On the Reduction of Certain Metals from their Solutions by Metallic Sulphides, and the Relation of This to the Occurrence of Such Metals in the Native State," *Trans. and Proc. New Zealand Institute,* Vol. III., 1871.

[2] Wilkinson, C., "On the Theory of the Formation of Gold Nuggets by Drift," *Trans. and Proc., Royal Soc. of Victoria,* Vol. VIII., pp. 11–15, 1867.

matter and showed conclusively that the phenomena were in no way dependent upon its presence. Upon immersion in dilute $AuCl_3$ solutions Skey obtained a deposit of gold upon the following: galena, monosulphide of iron (artificial), pyrite, chalcopyrite, covellite, sphalerite, stannite, molybdenite, cinnabar, sulphide of silver, stibnite, bismuthinite, sulphide of arsenic, sulphides of platinum and gold (artificial), arsenopyrite, and arsenide of silver. All of the deposits were obtained at ordinary temperature.

"A portion of the metal of the sulphide acted upon was uniformly found in the solution afterwards, and also sulphuric acid; the mode therefore in which these effects were produced was evidently by the oxidation of both constituents of the nucleus employed at the expense of the gold chloride. . . . it became of interest to ascertain whether or not other metallic salts (besides $AuCl_3$) were capable of being reduced by these, or by any of these substances.

"This part of the subject I have only slightly investigated, but enough has been discovered to show that silver and one or more of the metals of the platinum series are reduced from their soluble salts by these substances generally.

"Thus, silver is reduced from either its nitrate or acetate very readily by galena, copper pyrites, and the inferior sulphides of iron and copper." . . . "Cubic iron pyrites, also stibnite, has little or no effect upon silver salts, not even when heated with them; arsenide of silver has however a feeble effect."

Mercury and copper were not reduced to the metallic state by these same sulphides.

"When in place of this salt (chloride of gold) I applied the oxide of gold in solution of either potash, bicarbonate of soda, or silicate of potash, the effects were always the same; at least they were so with galena, sulphide of copper or protosulphide of iron. . . .

"The great deoxidizing power of the sulphides generally upon most gold, silver and platina salts, as manifested by the experiments just described, renders them so absorbent as it were of these metals, when presented to them as chlorides or oxysalts (the forms usually contemplated for them when in solution), that any such solutions traversing even a very thin vein or reef of the common metallic sulphides would in all probability be completely divested of these metals."

"Solutions of silver, however, would be little if any affected in traversing a reef of common iron pyrites or stibnite, alone, but if the solution contained gold in addition, it would be very probable that a certain portion of the silver would precipitate along with the gold by a simple chemical substitution."

Another line of investigation also inaugurated by Skey[1] involves the measurement of the electrical potentials developed when two metallic minerals are connected as poles of a galvanic circuit and immersed in some conducting liquid which does not react actively with them. This line of research has recently been followed by Gottschalk and Buehler[2] and by R. C. Wells.[3]

These writers have arranged the commoner metallic minerals in the order of the electrical potentials developed when they are in contact with a conducting liquid. Wells concludes that

"such potentials simply measure in an electrical way the oxidizing power of the solutions, the mineral playing a very insignificant part. . . . The potentials in metallic salt solutions depend entirely upon the nature and concentrations of the solutions."

It is now recognized that most reactions of oxidation and reduction may be effected by the use of the electric current in place of chemical agents, and conversely that an electric current may readily be produced by a proper arrangement of the components of any one of these reactions. As a consequence by measuring the relative strengths of the currents developed when various sulphides are successively connected as parts of a galvanic circuit it is possible to obtain a measure of the relative rate at which oxidation or reduction takes place. Such methods of study may prove useful in determining the relative efficiency of various minerals in reactions of the type described in this paper, but careful

[1] Skey, W., "On the Capability of Certain Sulphides to Form the Negative Pole of a Galvanic Circuit or Battery"; also "On the Electro-motive Power of Metallic Sulphides," *Trans. and Proc., New Zealand Institute*, Vol. III., 1871.

[2] Gottschalk, V. H., and Buehler, H. A., "Oxidation of Sulphides," Economic Geology, Vol. VII., 1912, pp. 15–34.

[3] Wells, R. C., *Jour. Wash. Acad. Sci.*, Vol. II., 1912, pp. 514–516. In abstract.

analytical studies are essential to their apprehension and for the present appear to form a more profitable line of research.

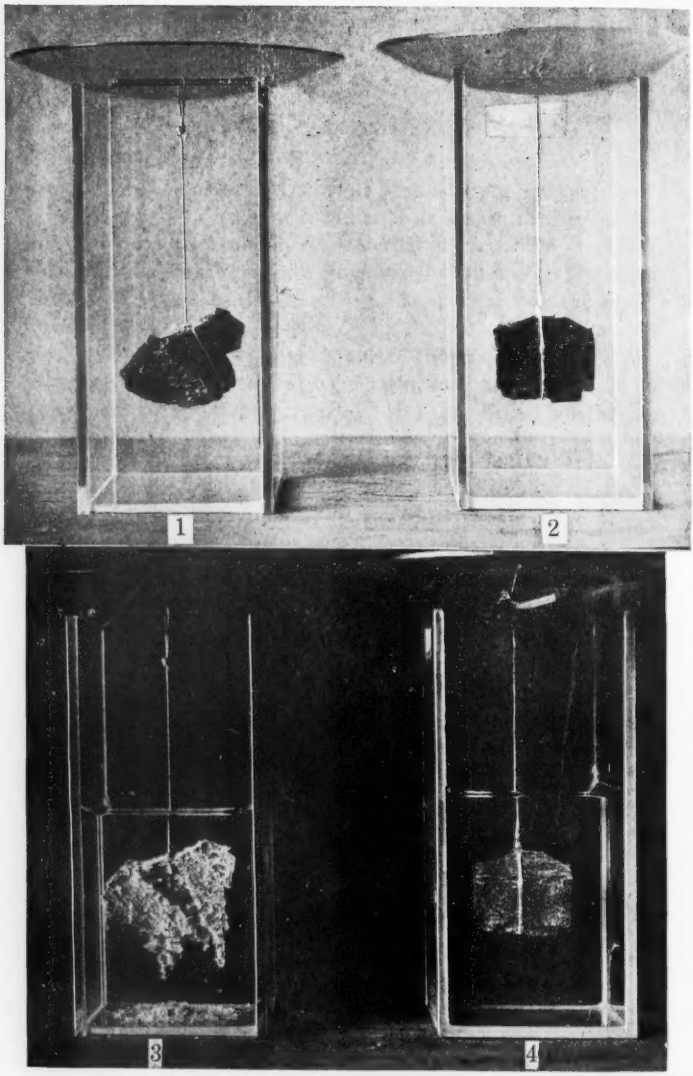
EXPERIMENTS.

WITH SILVER SULPHATE SOLUTIONS.

Conditions of Experiment.—In these experiments the minerals were selected so as to be as free as possible from admixtures of other minerals. Considerable variation is known to exist in the composition of natural minerals referred to the same species and such variation may influence greatly their efficiency as precipitants of the precious metals. As a matter of record, therefore, data are given in a footnote[1] showing the source of the material used. The experiments were conducted at ordinary temperatures. Pieces about ¼ c.c. in size were taken and were immersed in small evaporating dishes in 20 c.c. of 1/40 normal solution of silver sulphate. The solution was neutral at the beginning of the tests. The progress of the reaction was observed at intervals with the results recorded below, the minerals being arranged alphabetically. The data are summarized on pages 151 to 152 for the convenience of those to whom the details are unessential.

Alabandite: Within four minutes after immersion crystals of silver had developed in fair abundance. They were not flaky, as with covellite, but were closely attached to the mineral. After nineteen hours most parts of the specimen were coated with a thick frost of lustrous silver crystals, but aside from the develop-

[1] Alabandite, La Ilucha, Puebla, Mexico, U. S. N. M. No. 19565; arsenopyrite, State of Washington; gives profuse arsenic fumes before blowpipe; bornite, Aspen, Colo., U. S. N. M. No. 81851; chalcocite, Butte, Montana; chalcopyrite, Loon Creek district, Idaho; cobaltite, Buffalo mine; cobalt, Ontario, collection of F. L. Hess, U. S. G. S.; covellite, Butte, Montana; enargite, Butte, Mont., U. S. N. M. No. 85106; galena, Joplin, Missouri; jamesonite, Cornwall, England, U. S. N. M. No. 12500; marcasite, Joplin, Missouri; millerite, Gap mine, Lancaster Co., Pa., U. S. N. M. No. 83959; niccolite, Cobalt Lake mine, Cobalt, Ont., collection of F. L. Hess, U. S. G. S.; orpiment, Mercur mine, Mercur, Utah, U. S. N. M. No. 84708; pyrite, Gilpin County, Colorado; pyrrhotite, from pegmatite, Woodstock, Md.; realgar, Mineral Creek near Tacoma, Washington, U. S. N. M. No. 84752; smaltite, Cobalt district, Ontario; sphalerite, Joplin, Missouri; stibnite, Arkansas, collection of F. L. Hess, U. S. G. S.


1
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EXPLANATION OF PLATE.

PLATE II. This plate illustrates the efficacy of chalcocite as a precipitant of metallic silver from a solution of silver sulphate and the relative inertness of pyrite. The chalcocite is on the left and pyrite on the right. The upper set shows the minerals before immersion and the lower set shows them after they have remained 40 minutes in a 1/40 normal neutral solution of silver sulphate. The silver "tree" grows rapidly on the chalcocite and the experiment is a striking one for class-room use.

ment of silver no new mineral appeared to have formed. The solution gave only a faint acid reaction when tested with methyl-orange. With the ammonium persulphate test the solution reacted very strongly for manganese.

Arsenopyrite: After twenty minutes small crystals of silver were recognizable on several parts of the specimen and closely attached to it. In 1½ hours were recognizable small crystals which were only partially attached and waved as the solution moved. After thirty hours silver was developed in fair abundance over most of the surface in masses closely attached to the fragment, feathery forms not being present.

Bornite: Small crystals of silver began to form within thirty seconds after immersion. In ten minutes the fragment was largely covered with silver, some good-sized crystals having developed. After nineteen hours the piece was removed and when washed free of sliver appeared very fresh, no other reaction product than silver being recognizable. The solution had become pale green and gave an acid reaction with litmus paper. The speed of reaction is comparable with that with covellite.

Chalcocite: Within ten seconds after immersion in the silver solution a film of silver had developed over the mineral, and within thirty seconds minute crystals of silver could be observed. At the end of two minutes the whole fragment was brilliant silver white and some of the silver crystals had grown to considerable size. After 19½ hours the fragment was taken out of the solution. The silver film was gently brushed off with the finger and it was found that the mineral had a bluer tint than when immersed. The bluish frosting could be rubbed off with the finger, leaving the typical gray chalcocite surface exposed. The solution at the end of the reaction was pale green and acid in reaction toward litmus paper. Identical results were obtained with chalcocite from New London, Md. Lead acetate paper placed in contact with the mineral while the reaction was in progress gave no indication of the presence of H_2S.

Chalcopyrite: After 25 minutes immersion the specimen showed a slight peacock tarnish and a deposit of a little silver on one side.

After two hours a purplish-red tarnish had developed over the whole specimen. There had been some increase in the amount of silver, but this metal was not abundant and was confined to one face of the fragment. After twenty hours the specimen presented the appearance of a piece of bornite, the colors being royal purple, reddish bronze, and peacock blue. The silver did not seem to have notably increased over the amount present at the end of two hours. A sparse reddish-brown precipitate had collected in the bottom of the dish which was similar to that formed with pyrite but less abundant. This was tested and was found to be oxide of iron. The solution was not appreciably colored, but was faintly acid in reaction toward litmus paper.

Cobaltite: The formation of a red and orange coating suggestive of realgar and orpiment began at once on certain faces. After ten minutes this coating had become more abundant and a very dark brown coating had also formed on some parts of the specimen. The latter was associated with delicate skeleton crystals of metallic silver. After 3½ hours the silver, though partly in arboreal forms, was mainly in close-set plates or scales which were perpendicular to the surface of the fragment. Some of these showed a brownish color, due to admixture with the dark brown mineral which developed simultaneously. At this stage of the reaction the red and yellow coatings observed earlier were no longer visible. After 21 hours the whole specimen was covered with lustrous crystals of silver unmixed with any other material. It appears therefore that as the reaction progressed there was a variation in the nature and relative proportions of the reaction products. The fragment when washed free of silver showed some fresh-appearing cobaltite areas alternating with irregular patches of the dull, dark-brown mineral. The solution was not appreciably colored but gave an acid reaction toward litmus paper.

Covellite: Almost immediately upon immersion this mineral began to turn gray from the formation of a thin frost of silver. Within two minutes small crystals of silver were recognizable. In ten minutes numerous silver spangles had developed all over

the piece. In 1½ hours the piece was heavily coated with silver and the spangles had increased in size and abundance. After eighteen hours the specimen was taken out, washed free of silver, and examined. The surface of the mineral had lost the blue color typical of covellite and had become dark gray, sectile and shining black in streak. The nature of this alteration product is touched upon elsewhere in this paper. The solution had become pale bluish green in color and gave an acid reaction with litmus paper. In general the reaction though rapid was notably slower than that with chalcocite.

Enargite: Immediately upon immersion a gray frost of silver began to form. In one minute distinct crystals of silver were recognizable. In five minutes fair-sized crystals of silver were abundant and the specimen was entirely silver-plated. After 21 hours the fragment was removed and washed free of silver. It showed in places a thin peacock tarnish but otherwise appeared little altered. The silver had formed a thick moss-like aggregate. The solution was pale blue-green and gave an acid reaction toward litmus paper. Another fragment that had been in the same strength of silver sulphate solution for fifteen days showed a similar thin tarnish over portions of the surface when it was washed free of the silver crystals, but most parts of the surface appeared very fresh and unaltered. No precipitate except silver was formed in the dish. The speed of reaction is comparable with that for covellite.

Galena: After immersion for 21 hours no action was observable and the solution had remained neutral in its action toward litmus paper. At the end of seven days a small amount of silver had formed on the galena, particularly on angles of the fragment. The solution had become faintly acid in reaction toward litmus paper.

Jamesonite: After approximately seven hours minute crystals of silver were recognizable scattered over the surface of the fragment. After thirty hours there was still only a sparse scattering of minute crystals of silver.

Marcasite: After 25 minutes small crystals of silver were

found to be abundant on certain parts of the specimen. They clung closely to the surface and were not feathery or arborescent. After 19½ hours the silver had increased somewhat in abundance but still coated only small portions of the surface. The solution was uncolored but a reddish-brown precipitate, probably oxide of iron, had developed sparsely and setttled to the bottom of the dish. The solution gave an acid reaction toward litmus paper.

Millerite: No action was observable after immersion for 21 hours. The solution remained neutral toward litmus paper.

Niccolite: Within two minutes after immersion small slender arborescent crystals of silver were seen developing over most of the specimen. In ten minutes the crystals had grown to considerable size and a gray metallic mineral was also observed to be developing in minute crystals on the niccolite. The silver and the gray mineral appeared to develop simultaneously and gave a mixture of a dirty gray color. After three hours large and remarkably beautiful skeleton crystals of silver had developed, very different from the plate-like silver crystals developed with many of the minerals experimented with. After 23 hours the fragment was removed and washed free of silver. This exposed the fresh niccolite surface in places but elsewhere a coating of the black mineral remained. The solution appeared very faintly greenish and gave an acid reaction toward litmus paper.

Orpiment: After thirty hours immersion no deposit of silver was recognizable. Some parts of the specimen had darkened slightly.

Pyrite: After eighteen hours immersion the pyrite fragment had not changed in appearance, and no silver had formed. A small amount of reddish precipitate had, however, deposited in the bottom of the dish. This was tested and was found to be oxide of iron. The solution was faintly acid in reaction.

Pyrrhotite: After twenty minutes immersion minute crystals of silver had formed sparingly on most sides of the specimen. After twenty hours the silver had notably increased in abundance. It was not white but tarnished brownish, possibly by the

action of hydrogen sulphide liberated during the reaction. The whole surface had become somewhat more purplish in hue and the silver was developed mainly at angles or along cracks on the surface. The reaction appeared roughly comparable in intensity with that for marcasite and arsenopyrite.

Realgar: No action recognizable after 24 hours immersion.

Smaltite: No important change was noted for twenty minutes after immersion. At the end of that time small crystals of silver had begun to form in places and also a frost of a greenish yellow mineral. At the end of 1½ hours both of these reaction products had become very abundant. In 3¼ hours lichen-like forms of silver crystals had developed while other silver crystals clung closely to the specimen. At the end of twenty hours the reaction products were more abundant, but had not changed in character, except for the development of a black coating on some of the silver crystals. The solution was uncolored and was acid in reaction toward litmus paper. The speed of reaction was notably less than for either niccolite or cobaltite.

Sphalerite (resinous variety): No action was observable after 21 hours immersion. At the end of this period the solution was neutral in its action toward litmus paper. Another specimen which had remained in the same strength of solution for thirteen days also showed no action.

Stibnite: The piece that had remained in the silver solution for fifteen days showed no action whatever. The solution was clear and neutral in its action toward litmus paper. The fragment was not distinguishable in appearance from a piece from the same locality which had not been immersed in the silver solution.

Tennantite (largely free from antimony): At the end of 25 minutes small plates of silver had developed abundantly on the mineral and also a bluish-black mineral in very minute crystals. In 1½ hours the surface had not become silver plated but presented a mottled appearance, due to the alternation of areas of silver crystals with areas coated by the bluish-black mineral. After 21 hours the specimen was removed and washed free of silver. The bluish-black coating remained and in some lights

showed bluish and reddish iridescence. The solution had become very pale blue-green and gave an acid reaction toward litmus paper. In general the reaction was somewhat slower than for enargite.

EXPERIMENTS WITH OTHER SILVER SOLUTIONS.

The silver sulphate solution used in the experiments just described was neutral. In order to determine the effect of acidity upon the reactions, a solution of silver sulphate was rendered acid by the addition of sodium acid sulphate ($NaHSO_4$) and its action on chalcocite, chalcopyrite, and niccolite was observed. No marked difference was noted in the speed of action of the acid and neutral solutions. A minor feature of interest was the development of delicate feathery silver crystals in the chalcocite immersed in the acid solution, while that developed in the neutral solution formed brilliant spangles.

In order to approach more closely the conditions actually found in certain ore deposits a solution was made up which except for its silver content corresponded in composition to the vadose water collected by Weed[1] from the second level of the Mountain View mine at Butte. This water was dripping from the roof of the drift and was depositing chalcanthite. The artificial solution had the following composition:

$$\left.\begin{array}{l} CuSO_4 \cdot 5H_2O = 180 \text{ grammes} \\ ZnSO_4 \cdot 7H_2O = 2 \text{ grammes} \\ Ag_2SO_4 = \text{less than } 4 \text{ grammes} \end{array}\right\} \text{per liter.}$$

Chalcocite, bornite, covellite, galena, chalcopyrite, and niccolite were treated with this solution and silver appeared to be precipitated as rapidly as from the neutral silver sulphate solution. With the neutral silver sulphate solutions galena precipitated only very minute amounts of silver after many days immersion. With the cupriferous silver solution the action was more rapid though still slow as compared with the other minerals

[1] Weed, W. H., "Geology and Ore Deposits of Butte District, Mont.," Prof. Paper U. S. Geol. Survey No. 74, p. 101, analysis F.

tested. In general the presence of copper in the solution appeared to facilitate rather than to retard the silver precipitation.

A simple experiment with solutions of silver benzol sulphonate was performed to illustrate the rôle of hydrolytic action in reactions of the kind under investigation. This sulphonate is very soluble in water; if chalcocite is immersed in a saturated solution of the salt, silver is precipitated only with extreme slowness; if, however, the solution is diluted with thirty volumes of water silver begins to deposit rapidly and the reaction continues until the silver has been completely removed from solution. In the equation given on page 154, representing the reaction of silver sulphate solution on chalcocite, no account is taken of the part which the elements of water play in the changes involved. That water does enter into the reactions is clear from this experiment.

SUMMARY FOR SILVER.

Silver sulphate was chosen as the reagent in these experiments because it is well known that the solutions of the oxidized zone in sulphide ore deposits are sulphate solutions and also because the sulphate is much more soluble than either the chloride or the carbonate, the relative solubility in water at 25° C. being approximately as follows:[1]

Silver chloride	0.002	Grammes per liter.
Silver carbonate	0.033	
Silver sulphate	8.01	

The experiments reveal notable differences in the efficiency of the sulphides and arsenides tested as agents for the reduction of metallic silver from dilute aqueous solutions of its sulphate. In tentatively grouping the minerals tested according to their efficiency it is recognized that the speed of the reaction could only be roughly estimated by the methods used and that some of the minerals carried impurities which may have had an important influence on their activity.

[1] A. J. Cox and R. Abegg, *Zeit. fur. Phys. Chem.*, Vol. XLVI., p. 11, 1903.

[2] The cobaltite used was known to contain considerable amounts of nickel and the activity observed may be due partly or wholly to the nickel mineral present.

Very Strong.—Chalcocite, niccolite.

Strong.—Covellite, enargite, bornite, tennantite, alabandite, and possibly cobaltite.[2]

Moderate.—Smaltite, marcasite, pyrrhotite, chalcopyrite, arsenopyrite.

Weak or Inactive.—Cinnabar, stibnite, pyrite, galena, millerite, sphalerite, jamesonite, orpiment, and realgar.

The experiments show that reactions of the type under discussion can take place in acid as well as in neutral solutions and in waters that have the composition of certain vadose mine waters.

QUANTITATIVE EXPERIMENTS.

NICCOLITE AND SILVER SULPHATE SOLUTION.

The niccolite used in these experiments has the composition:

Ni	28.26%
Co	12.25%
Fe	.46%
As	53.02%
S	5.89%
	99.88%

Weighed quantities of the finely powdered mineral, niccolite, were digested in dilute silver sulphate solutions containing known amounts of silver sulphate. Action began promptly. Free silver was deposited and the solution became green. After the lapse of several hours the gray residual mineral together with the silver deposit was collected on a filter. After deducting the weight of the silver, the mineral residue was found to represent 35.12% of the niccolite treated. It consisted of cobalt, iron, arsenic, and sulphur distributed as follows:

Co	12.25%
Fe	.46%
As	16.52%
S	5.89%
	35.12%

The composition of this unattacked residue obtained from the so-called niccolite corresponds to the formula for cobaltite, namely, $Co(As[S])_2$.

The weight of silver deposited with the residual cobaltite amounted to 260.1% of the weight of the niccolite treated.

The portion of the mineral dissolved by the silver sulphate solution consisted of nickel and arsenic. The nickel amounted to 28.26% and the arsenic to 36.50% of the original mineral. Since these results correspond to one atom of arsenic for every atom of nickel dissolved, it is apparent that the material attacked by the silver sulphate solution is niccolite (NiAs). The arsenic was oxidized to arsenious acid. Since the dissolved nickel, dissolved arsenic, and deposited silver are, proportionally, nickel, one atom, arsenic, one atom, and silver, five atoms, the reaction between niccolite (NiAs) and dilute silver sulphate solution may be expressed by the equation

$$2NiAs + 5Ag_2SO_4 + 3H_2O = 2NiSO_4 + As_2O_3 + 3H_2SO_4 + 10Ag.$$

From these considerations the so-called niccolite may be regarded as consisting of 64.76% of true niccolite and 35.12% of true cobaltite. That silver sulphate solution may be used advantageously to throw light on the nature of certain complex minerals is apparent, for by its agency two distinct mineral species, cobaltite and niccolite, have been quantitatively parted. In the original specimen which contains both cobalt and nickel, apparently as inseparable companions, it is noteworthy that the silver sulphate solution assigns all the cobalt to the sulpharsenide, cobaltite, and places all the nickel in the simple arsenide, niccolite. The pyritous structure of true cobaltite may account for its failure to yield to the oxidizing action of dilute silver sulphate solution.

CHALCOCITE AND SILVER SULPHATE SOLUTION.

That free silver is deposited if metallic sulphides are digested in a silver nitrate solution has been mentioned by several observers, but their statements concerning the products lack unanimity. For instance, Skey implies that not only is the metallic radicle of the sulphide mineral dissolved by the silver solution, but its sulphur is also oxidized to sulphuric acid.

Heumann[1] observes that from artificial cuprous sulphide (Cu_2S) free silver is deposited and a gray powder which he considers to be silver sulphide. Schneider[2] corroborates Heumann. S. Meunier[3] states that he observed free sulphur among the products of the action of silver and gold solutions on several metallic sulphides.

In view of these divergent statements concerning the action of sulphides on silver solutions, it seemed advisable to determine the action of chalcocite on dilute silver sulphate solution. In no case was free sulphur formed, but the sulphur of the chalcocite was retained and held in combination as silver sulphide.

Total Ag deposited = 255.14% of chalcocite decomposed.
S in residue = 18.34% of chalcocite decomposed.
Cu dissolved = 75.81% of chalcocite decomposed.

These figures correspond to sulphur, one atom, copper, two atoms, and silver, four atoms. The reaction may be expressed by the equation

$$Cu_2S + 2Ag_2SO_4 = 2CuSO_4 + Ag_2S + 2Ag.$$

Although water does not appear in this equation it is believed, as already stated, that hydrolysis plays an essential part in the reaction. In a dilute silver acetate solution chalcocite acts in like manner.

Covellite containing 66.06% copper and 33.87% sulphur immersed for four days in a dilute silver sulphate solution gave up only 54.97% copper. This loss of 83.2% of its copper and deposition of an equivalent amount of silver as free silver and silver sulphide suggest that a more intimate structural relation exists between chalcocite and covellite than is indicated by the conventional formulas Cu_2S and CuS which are used respectively to represent the molecular masses of these two minerals. The study of the constitution of covellite is now in progress.

[1] *Berichte deutsch. Chem. Gesellsch.*, 7 (1874), p. 1680.
[2] *Pogg. Annalen der Physik*, Bd. 152 (1874), p. 471.
[3] *Compt. Rend.* (84) (1877), p. 638.

EXPERIMENTS WITH GOLD.

Conditions of Experiment.—The minerals used were from the same localities as those used in the tests with silver. The experiments were conducted at ordinary temperatures. Pieces about ¼ c.c. in size were taken and were immersed in small evaporating dishes in 20 c.c. of gold chloride solution, carrying about 7 gm. of gold per liter. This solution was slightly acid. The progress of the reactions was observed at appropriate intervals with the results recorded below. The minerals were arranged alphabetically with results which are summarized on page 159.

Alabandite: Yellow gold began to be deposited on the fragment immediately on immersion. Though forming skeleton crystals on certain parts of the piece, it was only after prolonged immersion that the whole surface was coated. When examined after 21 hours immersion the whole piece was coated but to very uneven thicknesses. The solution remained yellow.

Arsenopyrite: Within one minute the specimen became completely plated with yellow gold. The speed of reaction was comparable with that for galena and much greater than that for pyrite. When examined at the end of 17½ hours the original coating of yellow gold had become covered by a thick coating of dark brown arboraceous or mammillary gold similar to that developed on chalcocite. The solution had become colorless from the complete removal of the gold and tests showed the presence in it of both iron and arsenic.

Bornite: A coating of brown gold began to deposit on the specimen immediately upon immersion and in one minute the piece was completely coated. After fifteen minutes the brown gold coating was seen to be loosely mammillary in structure. The solution assumed a greenish-yellow color as the reaction progressed and when examined at the end of 66 hours had become light blue-green. All the gold had apparently been precipitated.

Chalcocite: The specimen which was dark gray at the beginning became bronze-colored immediately upon immersion and in one minute was dark brown in color. In one hour the solution had changed from golden-yellow to greenish-yellow. In two

hours the structure of the brown gold coating was seen to be loosely mammillary. After 23 hours immersion the brown gold coating was very heavy and the solution was light blue-green in color. All the gold had apparently been removed.

Chalcopyrite: After four minutes immersion distinct crystals of yellow gold had developed abundantly over most of the specimen. The deposition apparently took place slightly more rapidly than with pyrite. After one hour the specimen was still not wholly plated. After three hours the piece was heavily enough plated so that it had the appearance of a gold nugget. It was then removed. The gold was slightly redder in tint than that developed on pyrite, but not so red as that deposited on enargite.

Cinnabar: At the end of two hours no action could be observed. After 22½ hours small crystals of gold were observed scattered over the surface. After three days gold had deposited over nearly half of the surface giving a mottled appearance. The solution remained yellow.

Cobaltite.—Within three minutes the cobaltite was almost wholly coated with yellow gold. After 19½ hours the gold coating had become brown and thick showing an arboraceous or loosely mammillary structure. A little calcite occurred mixed in small grains with this cobaltite, and the action of the acid in the solution on this generated bubbles of CO_2. It is interesting to note that lustrous gold precipitated upon the surface of these bubbles. Broken shells of gold remained where some of the bubbles had burst. The solution had become nearly colorless through the complete extraction of the gold from the solution. All lustrous gold present with the brown gold was attributed to the action of the calcite present as an impurity.

Covellite: The specimen began to tarnish immediately upon immersion and in two minutes small skeleton crystals of gold had developed. After 20 minutes the gold coating was still very thin. It gave a pure golden-yellow color in only a few places. After 92 hours the fragment was still only thinly and partially gold-plated and the solution was still golden yellow, showing that only a portion of the gold had been precipitated. The gold formed was light yellow in color.

Enargite: Gold began to deposit on the specimen immediately upon immersion and after one minute the piece had become almost wholly gold-plated. After two hours the fragment was removed; at this time it was completely plated with orange-yellow gold. The solution was still golden-yellow.

Galena: Gold began to deposit on the specimen immediately upon immersion, the action being more rapid than for pyrite. After three minutes the piece was completely plated with yellow gold. The solution was golden-yellow even after the galena had remained in it for four days.

Marcasite: Some yellow gold was deposited within one minute after immersion. The reaction is roughly comparable to that with pyrite. When examined at the end of 48 hours the specimen was wholly gold-plated and the solution was still golden-yellow in color.

Millerite: After four minutes immersion most parts of the specimen had become coated with yellow gold. After thirty minutes the piece was completely plated with gold similar in color to that formed on pyrite. After 2½ hours the piece was removed. The solution was still golden-yellow in color.

Niccolite: Orange-yellow gold began to deposit on the specimen immediately upon immersion and in fifteen minutes the specimen was wholly coated. After twenty hours some arboraceous growths of somewhat browner gold had developed in addition to the gold plating. After 68 hours the solution was still golden-yellow in color.

Pyrite: After eight minutes immersion a thin film of gold had formed on most parts of the specimen giving it a greenish tint. After forty minutes the plating was still so thin that the fragment had a color intermediate between gold and pyrite. After four hours most parts of the piece had the lustre of yellow gold but a few patches were still only thinly plated and greenish.

Pyrrhotite: After three minutes a thin iridescent film of gold had formed. In ten minutes the coating had increased in thickness, become greenish or bronze-colored, and small distinct crystals of gold were also visible. After 3½ hours most of the speci-

men was thickly gold-plated and showed the characteristic yellow color of that metal; on other parts, however, the coating was very thin and the surface had a greenish tint.

Smaltite: Yellow gold began to deposit almost immediately upon immersion, but less rapidly than for cobaltite. In ½ hour most but not all of the smaltite was coated. Some calcite occurring mixed with the smaltite as an impurity, carbon-dioxide bubbles were evolved and resulted in the precipitation of some lustrous yellow gold, as was the case with cobaltite. When examined at the end of 48 hours the yellow gold had become covered by a heavy coating of arboraceous dark brown gold and the solution had become colorless through the complete removal of gold.

Sphalerite: After 55 minutes a thin deposit of yellow gold had formed on certain parts of the specimen. After four hours the gold plating had spread somewhat, but was still absent from the lustrous cleavage surfaces. To determine to what extent the lustrous character of the cleavage faces inhibited deposition, a scratch was made on one of these surfaces with a knife point; further immersion resulted in the deposition of gold on this scratched portion but not on the lustrous face. After four days the more lustrous faces were still free from gold and the solution remained golden-yellow in color.

Stibnite: There was no action certainly recognizable after three minutes immersion. After fifteen minutes a coating of bronze-colored gold somewhat yellower than that developed on chalcocite mottled the specimen. After one hour fully three-fourths of the surface was so coated. After three hours the piece had become wholly coated. After ten days the solution was still yellow, and the gold had not been wholly removed.

Tennantite (largely free from antimony): Within one minute after immersion the specimen had turned bronze-colored from the deposition of a film of gold. In twelve minutes it had become almost completely plated with yellow gold. After eighteen hours the gold coating had assumed a more orange-yellow tint similar to that of the gold deposited on chalcopyrite. The solution remained golden-yellow in color.

SUMMARY FOR GOLD.

The gold precipitated by the action of chalcocite, bornite, arsenopyrite, niccolite, cobaltite, and smaltite was mainly dark-brown and porous and the reaction continued until all the gold of the solution had become exhausted. The gold developed on pyrite, chalcoyprite, marcasite, galena, millerite, enargite, tennantite, pyrrhotite, alabandite, covellite, sphalerite, and cinnabar was yellow and compact. The deposition of yellow, compact gold over the whole surface appeared to protect the mineral from further action of the solution and thus to retard and finally terminate the action, so that all of the gold in solution was not deposited and the solution remained yellow.

Under natural conditions the sulphides would seldom become completely coated with gold and the inhibitory action due to such complete plating would not be felt.

All of the metallic minerals tested that were efficient as precipitants of silver were also efficient as precipitants of gold.

Galena, pyrite, stibnite, and millerite which were inefficient as precipitants of silver were active as precipitants of gold.

Sphalerite and cinnabar acted only weakly in precipitating gold.

EFFECTS OF THIN COATINGS OF CUPROUS SULPHIDES.

The occurrence of very thin films of gray secondary chalcocite on chalcopyrite is a common phenomenon in the upper portions of many ore bodies. A specimen from Gilpin County, Colorado, showing such films was treated with silver sulphate solutions. The chalcopyrite precipitated silver with extreme slowness, but the thin chalcocite coating was a very efficient precipitant. The reaction forms in fact a convenient means of identifying such gray coatings as, probably, chalcocite when they are too thin to be detached and tested.

Peacock-colored coatings are also common on the chalcopyrite of some veins and such coatings may be readily produced artificially by placing a piece of chalcopyrite in contact with an iron nail in a solution of copper sulphate. A piece so tarnished will precipitate silver and gold with great readiness, whereas the un-

coated chalcopyrite acts only very slowly. It is clear therefore that thin films of cuprous sulphides on chalcopyrite or other minerals may be almost as efficient as larger bodies of such sulphides in precipitating the precious metals.

APPLICATION IN ORE DEPOSITS.

ASSOCIATION OF NATIVE SILVER WITH COPPER ORES.

The results recorded above find their principal counterpart in nature in the phenomena of the oxidized zone and the zone of downward sulphide enrichment in ore deposits. The subject is a large one and it is only necessary here to cite a few examples to show the influence of such phenomena upon the distribution of values in ore deposits.

If chalcocite exercises such a strong precipitative action upon the precious metals when these are carried in neutral or acid solutions, we should expect that the precious metals would be reprecipitated as soon as they reach the upper part of the chalcocite zone. Although most of the great copper deposits of the world in which chalcocitization has been observed carry only low values in gold and silver in the original ore, such evidence as is available indicates that the chalcocite *has* exerted a precipitative influence upon the precious metals.

In the copper veins of Butte, Montana, there are present nearly all of the copper minerals which these experiments have shown to exert a strong precipitative action on silver and gold. Here the conditions should have been almost ideal for testing the efficiency of such action under natural conditions. Unfortunately, the precious metal content of the original ores is very low and not very full information is available in regard to the occurrence of precious metals in the upper portions of the copper veins. In the Butte folio appears the following statement:

> "Native silver has been found in both the copper and the silver mines. It is the only silver mineral that it has been possible to recognize in the copper veins."

This statement at once suggests the efficiency of the copper minerals in reducing silver salts in solution to the metallic state.

According to Weed:[1]

"Native silver is common in the silver veins and also in the oxidized portions of the copper veins. It has been observed in mossy aggregates and coatings in fracture planes in glance (chalcocite) ores, and in bornite. Wire silver and fibrous silver also occur in cavities in bornite and glance (chalcocite), particularly in the upper levels of the Parrot mine."

Another line of evidence consists in a comparison of the average silver values in the upper and lower portions of certain veins. Weed states[2] that for the upper levels of the Gagnon mine at Butte the ore carried an average of three ounces of silver to each per cent. of copper, whereas the average silver content of the ores extracted from lower levels in 1905–6 was only half as great, namely ½ ounces of silver to each per cent. of copper.

A report by Pearce on the Gagnon mine is also suggestive.[3] Pearce reports the occurrence of native silver in very thin plates throughout masses of "cupriferous zinc-blende" which he believed to be wurtzite in part, from between the 200 and 300-foot levels of the Gagnon mine. What was regarded by Pearce as a single mineral from the 500-foot level of the Gagnon mine gave the following assay:

	Per Cent.	Molecular Proportions.
Copper	41.10	.646
Silver	24.66	.228
Zinc	9.80	.15
Iron	2.09	.137
Sulphur	20.51	.64
Insoluble	1.02	

As no compound of copper and silver approaching this composition is known, it seems very probable that this does not represent a single mineral, but is a mixture of a copper sulphide with silver or silver sulphide. Pearce also mentions a specimen from another part of the Gagnon mine having the properties of enargite but

[1] Weed, W. H., "Geology and Ore Deposits of Butte District, Montana," Prof. Paper U. S. Geol. Survey No. 74, p. 68.

[2] Ibid., p. 68.

[3] Pearce, Richard, "The Association of Minerals in the Gagnon Mine, Butte City, Montana," *Trans. Amer. Inst. Min. Eng.*, Vol. 16, 1877–78, p. 63.

containing ten per cent. of silver. Bornite, which occurs sparingly in the upper part of the mine, he reports to be rich in silver, while chalcopyrite is usually low in silver.

It appears probable therefore that the precipitative action of chalcocite and other sulphides of copper played some part in the localization of the silver values in the upper portions of the Butte copper veins.

The intimate association of bornite, chalcocite, and native silver has been noted by one of us[1] in the Up-to-Date mine near Caribou, Boulder County, Colorado. The rich ores of that mine carry chalcocite, bornite, native silver, and calcite (non-manganiferous) as their principal minerals with subordinate amounts of covellite. The ores of this type thus far obtained were found within

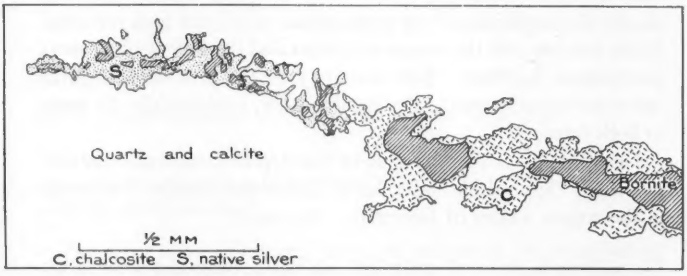

FIG. 9. An example of the contemporaneous deposition of chalcocite, bornite and native silver as secondary minerals. Camera lucida drawing of replacement veinlet in altered pyroxenite from the Up-to-Date tunnel, Caribou, Colorado. The average width of this veinlet is about ¼ mm. and its length 2 cm. A neighboring veinlet of similar character is traceable for a length of 8 cm.

50 to 100 feet of the surface and occur as small veinlets in, and as replacements of, altered pyroxenite. Some of the veins are an inch or so in width and one of them yielded a specimen of native silver 6 by 8 inches by ¼ to 1 inch thick. From this size they grade downward to exceedingly minute veinlets less than 1 mm. wide. One of the latter greatly magnified is shown in Fig. 9. Its irregular form shows that it probably developed by

[1] E. S. Bastin.

metasomatic replacement of the rock proceeding outward from a very minute fracture. The irregular mode of association of the native silver and the sulphides indicates that they were contemporaneous crystallizations. Covellite, when it occurs, is intergrown with bornite or chalcocite. It bears no relation to vugs or cracks and seems to have crystallized with the other sulphides.

There is little doubt that the rich silver-copper veins of this mine are the result of downward sulphide enrichment, the materials being supplied by primary galena, sphalerite, chalcopyrite, calcite veins, and other chalcopyrite, pyrite, quartz veins which are also exposed in these workings. The detailed evidence of such origin is not germane to the present discussion. In most of the natural occurrences previously described, the native silver was deposited distinctly later than the sulphides, simulating closely the conditions of the experiments which are here reported. In the present case the copper sulphides and the native silver were precipitated together. The chemistry of the process as regards the reduction of silver to the metallic state, is essentially the same in both instances.

Occurrences similar to that in the Up-to-Date mine are not extremely rare. Beck[1] described a similar association of minerals in the copper shales of Germany. He says:[2]

"In addition to the small grains [of sulphides], there also occur in the *Kupferschiefer* fine bands, mostly parallel to the bedding, of bornite and chalcocite, and along bedding-planes and cross-fractures, coatings of chalcocite, bornite, chalcopyrite, and native silver."

These instances, while by no means exhausting the literature, suffice to show that the association of silver with chalcocite, bornite, and related copper minerals has been frequently noted. Doubtless the presence of native silver in intergrowth with such copper minerals will be found to be a common phenomenon as more copper ores are studied microscopically in the polished sections.

[1] Beck, "Lehre von den Erzlagerstätten," II., p. 155, 1909.
[2] Translation by E. S. B.

In his report on the Bingham district, Utah,[1] Boutwell figures (Pl. 38–*C*) a piece of ore from the Commercial mine. He says:

"A central band of cupriferous pyrite containing a trace of tellurium and low values in copper, gold, and silver is enclosed by bands of chalcocite and tenorite forming the outer portion of the vein containing considerable tellurium and high values in copper, gold, and silver."

The cupriferous pyrite of this specimen yielded:

Gold	0.01 oz.
Silver	3.32 oz.
Copper	a little.
Tellurium	trace.

The black sulphide (namely chalcocite) yielded:

Gold	3.80 oz.
Silver	58.60 oz.
Copper	42.3 %

and a proportionately increased amount of tellurium.

"This goes to show that not only are the copper values thus highly raised by enrichment, but that gold and silver believed to occur as tellurides are proportionately enriched."

The writers of this paper have not succeeded in precipitating tellurium from its solutions by means of chalcocite, but as both tellurium and chalcocite will precipitate gold from its solutions, the association of both gold and tellurium with secondary chalcocite is not surprising.

ASSOCIATION OF NATIVE SILVER WITH COBALT AND NICKEL ARSENIDES.

The experiments showed that niccolite and, to a lesser degree, smaltite and impure cobaltite are comparable with chalcocite, bornite, and covellite in the strength of their reducing action upon an aqueous solution of silver sulphate.

[1] "Geology of Bingham Mining District, Utah," Prof. Paper U. S. Geol. Survey No. 38, pp. 218–222 and 268, 1905.

The frequent association of native silver with nickel and cobalt arsenides is too well known to require lengthy comment. It is perhaps sufficient to cite as an example the Cobalt District of Ontario. S. F. Emmons[1] in describing this district says:

"The more common minerals of the rich vein deposits are the arsenides of cobalt and nickel, smaltite with some chloanthite, cobaltite, and niccolite, associated with native silver. Less frequent are native bismuth, the silver minerals pyrargyrite, proustite, dyscrasite, and argentite, the nickel sulphide, millerite, with occasional mispickel and tetrahedrite. The ordinary sulphides pyrite, galena, and zincblende are occasionally found in the wall-rocks but apparently do not form an essential part of the deposits. The gangue minerals are calcite with a little quartz, but both are in relatively subordinate amounts in the rich parts of the veins."

"It is generally recognized that the native silver is of distinctly later deposition than the cobalt-nickel arsenides—indeed, the evidence in the mines is most conclusive. . . . Very often minute cracks may be seen crossing the cobalt minerals and gangue rocks which are filled with films of native silver, and the flake or sheet form in which the silver is so often found shows that it has grown in such cracks."

In the experiments conducted with cobaltite and smaltite, one or more reaction products, in addition to native silver, were abundantly developed. Although the nature of these other products has not been determined it is suspected that some of them are silver salts and it is noteworthy therefore that several other silver minerals besides native silver are present in the cobalt veins.

ASSOCIATIONS OF NATIVE GOLD WITH SULPHIDES.

Without touching the question of the apparent preference manifested by gold for certain sulphides in deposits that are clearly primary, it is possible to cite numerous instances where the sulphides seem to have exerted a reducing influence during the process of secondary enrichment.

Mr. Reno Sales[2] has found distinct and fairly good-sized particles of native gold on the surface of chalcocite crystals from

[1] Emmons, S. F., "Cobalt District of Ontario," in "Types of Ore Deposits," published by Mining and Scientific Press, 1911, pp. 141 and 143.

[2] Cited by Weed, Prof. Paper U. S. Geological Survey No. 74, page 79.

the 1,000-foot level of the Leonard Mine at Butte. The high gold values in secondary chalcocite in the Commercial Mine at Bingham, Utah, have already been referred to (page 165).

In describing secondary enrichment in the pyritic deposits of Huelva, Spain, Finlayson says:[1]

"The lower limit of the gossan is sharp and well-defined and the line of contact between the gossan and sulphide ore is sometimes marked by an earthy zone carrying considerable values in gold and silver. This has been described by J. H. L. Vogt, who has pointed out that it represents a concentration, during secondary enrichment, of the traces of gold and silver in the original ore, the precious metals dissolved in ferric sulphate being precipitated by the reducing influence of the pyrite."

SUMMARY AND CONCLUSIONS.

While the reducing action of organic matter, of ferrous sulphate, and of hydrogen sulphide have been often invoked to account for the deposition of native gold and silver from ore-forming solutions, the efficiency in this respect of the metallic minerals which form the ore itself has not been sufficiently recognized.

The preliminary experiments here described show that certain sulphides and arsenides of copper and nickel, precipitate metallic silver very efficiently from dilute aqueous solutions of silver sulphate. As the waters descending through the upper portions of most sulphide ore bodies are known to be sulphate waters, similar precipitative action under natural conditions is to be expected. In natural mine waters gold and silver are present in amounts too small for duplication in laboratory practice and such duplication is needless because the phenomena appear to depend largely on hydrolytic action and it is not probable that extreme dilution can inhibit the reactions which take place at the dilutions adopted in these experiments. That certain constituents found in mine waters do not inhibit the reactions is shown by the precipitations obtained from a solution simulating, except for

[1] Finlayson, A. Moncrieff, "The Pyritic Deposits of Huelva, Spain," ECONOMIC GEOLOGY, Vol. 5, 1910, pp. 409–410.

its silver content, a vadose mine water from Butte, Montana. The frequent association of silver in ore deposits with chalcocite and bornite, and particularly with niccolite, minerals which in these experiments were among the most efficient precipitants, warrants the belief that such reactions are of great importance in secondary enrichment of ore bodies.

The more common sulphides such as pyrite, galena, and sphalerite were relatively inactive as precipitants of silver from aqueous solutions of its sulphate.

The quantitative results obtained with niccolite and chalcocite indicate that the essential chemical changes in reactions of this type are due to oxidation through the process of hydrolysis.[1] *It is apparent therefore that certain water solutions may act as potent oxidizing agents below the ground water level.*

The experiments indicate that nearly all of the sulphides and arsenides common in ore deposits are capable of reducing gold from a solution of its chloride, although important differences in the rapidity of the precipitation were observed with different minerals. With certain minerals the gold formed was dark brown and porous and the reaction continued until all the gold in the solution was exhausted, while in other cases the gold was yellow and compact, and the protective plating of the specimen with this type of gold slowed down and eventually stopped the reaction before all the gold in solution had been deposited. This inhibitory action as a result of complete plating, and the added fact that the luster of the mineral influenced the rate at which it reacted with the gold solution, made it impracticable to classify the minerals in these tests as closely as in the silver tests. It is clear, however, that most of the minerals that are especially efficient as precipitants of silver are also effective precipitants of gold and that a number of other minerals such as galena, pyrite, stibnite, and millerite that are inefficient in precipitating silver are *efficient* in depositing gold.

It is known that the waters descending through the upper por-

[1] "The Nature of the Hydrolytic Process," by H. E. Armstrong and F. P. Worley, *Proceedings of the Royal Society, London*, Series A, Vol. 87, No. A. 599, 1912, pp. 604–623.

tions of sulphide ore bodies universally carry chlorides and it is probable that these chlorides have effected the solution of the gold. It is probable therefore that phenomena similar to those exhibited in the experiments with gold chloride solution play an important part in secondary enrichment in gold.

It is recognized that other constituents of mine waters may so change the quality of solutions as to render them capable of precipitating argentite, polybasite, proustite, etc., in excess of or to the exclusion of native silver. The origin of these secondary silver minerals constitutes a related problem, the solution of which is greatly to be desired.

While the phenomena here described find their most immediate application in secondary enrichment it is perfectly possible that such reducing effects of the sulphides may be responsible in part for the *primary* association of the precious metals with certain sulphides in preference to others. It is recognized of course that certain mineral associations in ore deposits are probably the result of processes analogous to differentiation in rock magmas, but it is quite possible that other associations such as the apparent preference of gold for chalcopyrite and tetrahedrite rather than for pyrite in deposits carrying these three minerals may be due to differences in the reducing power of these sulphides themselves. Light could probably be thrown upon this point by the investigation of the reducing effect of various sulphides upon silver and gold salts dissolved in solutions having the composition of certain deep mine waters. The effect of increase of temperature on the reactions should also be studied.

It is a generally recognized fact that the purity of alluvial gold is greater than that of the veins in the neighborhood. This superiority in fineness has generally been explained by the well-known fact that silver is more readily soluble in natural waters than gold, and is by them removed from the natural alloy, thus increasing its purity.

Lindgren has recently discussed this matter at some length in a report on the Tertiary gravels of California,[1] and has pre-

[1] Lindgren, W., "The Tertiary Gravels of the Sierra Nevada of California," Prof. Paper U. S. Geol. Survey No. 73, 1911, pp. 68–70.

sented a large amount of statistical data leading to the same conclusion. It has been thought by certain geologists that this refinement of the gold was accomplished by solutions circulating through the gravels themselves, but Lindgren states that

> "so far as the Tertiary gravels of California are concerned, the conclusion of the writer is that solution and precipitation of gold have played an absolutely insignificant part."

Under the conditions of the experiments here reported it was found that nearly all of the metallic minerals common in precious metal deposits are capable of precipitating gold, while a much smaller number, and these not the most common ones, are active precipitants of silver. When it is remembered that the source of the placer gold is the oxidized zone of the original deposit and that the gold may have been dissolved and redeposited several times within the vein before erosion carried it into the alluvium, it seems not improbable that such selective precipitation may have been one factor in this natural refining of gold.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

FIELD AND OFFICE METHODS IN THE PREPARATION OF GEOLOGICAL REPORTS.

GEOLOGICAL FIELD-METHODS.

The geologists now in middle life or approaching the emeritus age of the Carnegie Foundation seldom received instruction in the technique of the subject from their old-time professors. Instruction twenty-five to forty years ago was chiefly of the so-called cultural type. If a student manifested a special fondness or aptitude for geological work, his master was disposed, more often than not, to send him out by himself on a piece of work in order to test him and see if he developed intelligent methods of his own and the necessary staying qualities. Now, however, with the growth of university courses, which, leading to the Ph.D. degree in geology, are usually as severely professional as a law school or a school of medicine, a professor is looking ahead to the days when his students will be entering surveys, or doing field work for others, and when he will wish them to acquit themselves in a workmanlike manner. Actual instruction in the field and in the technique of the subject has become the normal order of a part of the preparation. In schools of mines, where geological training is fundamental and where it goes hand in hand with surveying, map-making, and kindred branches, some experience in field-work under competent guidance is indispensable. When instruction is given to either of these groups, some definite system of observing and recording is very desirable. Even if the

system used is not the best one, decided advantages accrue from insisting that an immature geological mind work accurately according to some definite plan. The field-training of a mining or civil engineer is of great parallel value, because it impresses accuracy and neatness of records in notebooks and because its influence is set against careless and sloppy work. Every one who sets out for his day in the open, and for that invigorating and wholesome life for which in the confinement of the laboratory and lecture room in the winter we all pine,—everyone has to guard against the exhilarating influences of the fresh air and the exuberant joy of life. It is more than easy to gallop along and think that what one sees will be easily remembered; and yet the old dictum of the engineering class-room of the writer's student days comes back with redoubled force: "A note on the spot is worth ten in the office."

In recording geological observations, the first essential is a map, and upon the excellence of the map depends the value of the results. Let us assume that we have that priceless boon, one of the U. S. G. S. topographical sheets of later years. It should be cut into cross-strips of such vertical height that they will be contained inside the cover of the notebook. The strips may be cut into rectangles which can be pasted on the pages of a notebook, said pages being of course of squared, cross-section paper; or each strip may be folded back once with the map-side out; and then each half doubled forward again with the map-side in. A W-shaped strip results which can be tied in the notebook and opened up like the leaves of a book.

In recording his observations and keeping track of them the field-worker may trace on his map the course he pursues and wherever he stops for a specimen and a record, may note on his map the number of the station in the entire series. By keeping parallel records in his notebook and carefully numbering his specimens he may work up his final map on a fresh sheet and know where everything was gathered. The number on his specimen does not mean anything, however, except as taken in connection with his map, and the endeavor to establish the locality in

the notebook would necessarily read something like this: "Walked south on road from Hunters' Home, Elizabethtown, about a mile and turned west on trail up Coughlin Brook one half mile to trap dike, Spec. 27, N. 45 E.—Vert., 6 ft. wide in anorthosite." If the geology is complicated and many traverses are made the lines may become confusing.

Should the cut strips be pasted on cross-section paper, letters may be placed between suitably spaced lines along the top and bottom, and numbers down the sides, so that by intersecting coördinates, as in the atlases, a spot may be approximately located. Or the map itself may be provided with the same. Not a few geologists adopt this plan.

Some years ago the writer brought before the Geological Society of America the following coördinate method which had proved very serviceable in personal field-work and with classes.[1] The map of a quadrangle, beginning with the outer northwest corner of the border is ruled in one inch squares, lightly with water-proof India ink. Every second vertical and horizontal line is then made double, so that while blocked in one inch squares as a whole, the map is also blocked in groups of four one-inch squares. One inch is selected because it is easily transferred from ordinary scales, and because it almost exactly represents one mile on the common scale of 1/62,500. The outer corner of the frame of the map is used because it is desirable to maintain the rectangular shape, and avoid the appreciable taper of the great circles of longitude. At the intersection of the single lines inside the double lined squares a number is written beginning with the northwest block as 1, and continuing horizontally across on the top row, with 2, 3, 4, 5, 6, and for the fractional square in our latitudes, 7. In the next horizontal row we begin beneath 1, with 11, and continue across with 12, 13, etc., so as to preserve the decimal and invariable arrangement. The bottom fractional row will begin with 81. Thus each of these numbers means a definite group of four square miles, accurately and similarly placed on each quadrangle.

[1] The method is more fully described under the title "Geological Bookkeeping," *Bulletin Geol. Soc. of America*, 16: 411–418, 1905.

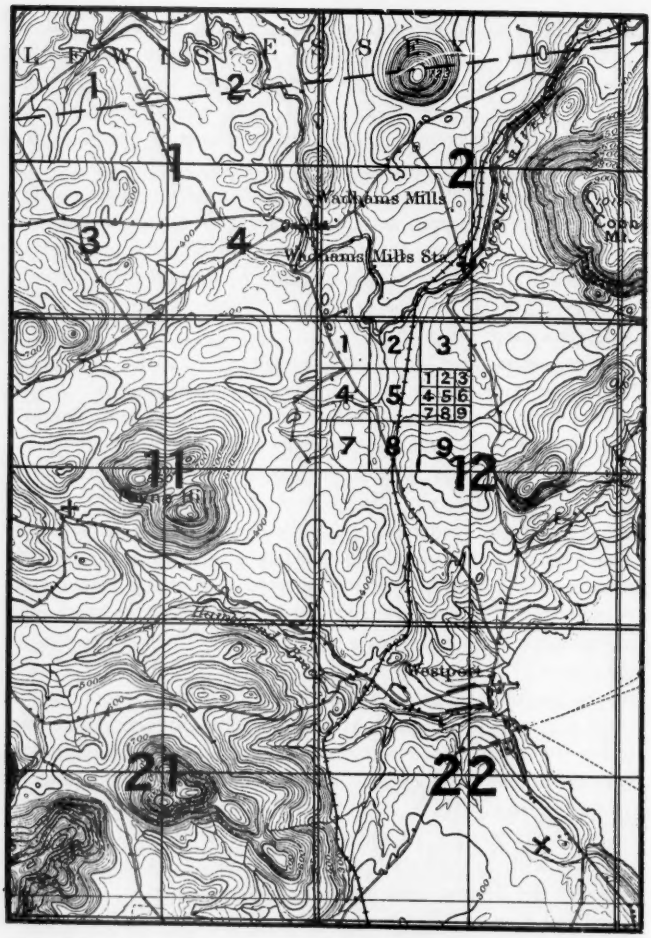

FIG. 10. Northwest corner of the Port Henry, New York, Quadrangle, illustrating method of recording notes. In a full U. S. Geological Survey topographic sheet the numbers would read 7, 17, 27, etc., in the right vertical column, and 81, 82, etc., to 87 below, in the lowest horizontal row. From *Bull. Geol. Soc. Amer.*, 16: 413, 1905.

We now number the four squares under each block, invariably upper left, 1, upper right, 2, lower left, 3, lower right, 4, but there is no need of placing this simple notation on the map. We then imagine each one-inch square divided into ninths, and numbered on the top row, from left to right, 1, 2, 3; on the middle row, left to right, 4, 5, 6; on the bottom row 7, 8, 9. We thus keep within single digits. There is no need to rule these on the sheet. They can be estimated. We may now further subdivide in our minds each ninth into ninths similarly numbered. All this is illustrated in Fig. 10 taken from the original paper. Thus, if one found an outcrop of anorthosite just south of Wadhams Mills Station, where the star appears, it would be in the Port Henry quadrangle, 2, 3, 6, 9 (read two, three, six, nine). In his notebook the observer would merely record, "2,369 Anorthosite, massive, coarse, spec. 178," and put a dot or a cross on his map. In the figure the plus sign is in 11,327, and the multiplication sign in 22,455.

It is also possible to make only every third line of the inch squares double, and enumerate them in blocks of 9 instead of 4. It is also possible to consider the rectangles of the quadrangular map, as blocked by the great circles of longitude and the parallels of latitude, the nine primary blocks, and then subdivide each of these into secondary, tertiary or finer subdivisions; but if we do this, we lose the square miles of the other plans, and these are a very useful scale of distance.

Suppose, now, a professor and his assistants are in the field with a party of students, possibly fifty or a hundred, subdivided into parties of ten, each with an officer over them to whom they report at night. Every student has his map, ruled like every other map in the party. Working by two's and each pair with a squad number, they are assigned as a rule to two square miles for the day's observations. Returning at night each captain of five pairs colors in on his map the results of each pair's observations and decides where the squads are to go the next day. The map gradually grows, the captains confer and make a collective map, and the student observers, seeing the total work of the entire party, are keen to learn what is in the still unexplored

areas. On a quadrangle exhibiting the wonderful structural features of the Appalachian folds, the experience is not only instructive but interesting in the highest degree. With a party of from 25 to 40 active pairs, in this organization, we have been able to overrun nearly two quadrangles in a week, with the result that a fairly good map has resulted. The officers of course spend the day with one pair and another in personal instruction. The invariable system of recording localities by the coördinates has proved of valuable disciplinary influence, and has given a unity of result which has been serviceable.

In the earlier paper it was shown that the coördinate method led also to a compilation book. The compilation book is a fresh blank book of larger size than the field notebook. Its pages are numbered to correspond with the squares, 1.1, 1.2, 1.3, 1.4; 2.1, 2.2, etc., and from the notebooks all the records made in each of these squares are copied on their appropriate page, and these arranged in order of the ninths. Thus, 1.1.1 comes at the top of the page and 1.4.9 at the bottom. In later field work with a loose-leaved notebook, the writer has began a fresh page for each new square-mile, appropriately numbering the page at the top. Ten or more pages might be taken for the same square mile and be given serial numbers under it. The field numbers of specimens can also begin with the number of the square where they are found. At the close of the day or of the trip the pages can be sorted out by square miles and then we have automatically together whatever has been seen and recorded in each. The labor of copying and compiling is avoided, and in working up the final map observations are grouped and classified as most needed. All this matter of compiling or systematically grouping becomes of greatest value when one's work in a region extends over a period of years, and observations on the same or adjacent areas are scattered through several notebooks. Indexes and cross-references are necessary if we have not some such plan as the compilation book. If several individuals or a large party in class-work are in the field, the compilation book yields a great advantage in bringing together widely scattered records.

J. F. KEMP.

A MODIFICATION OF THE ORDINARY FIELD METHOD.

Sir:—For the past three years I have been engaged in geological mapping on Vancouver Island for the Geological Survey of Canada, using as base maps previously prepared topographic maps on the scales of 1:62,500 and 1:125,000. The method of field work and note-taking employed is a modification of that in common use and seems to be well adapted to rapid geological surveying on the above mentioned scales. Its chief advantages are the preparation of a map in the field upon which virtually all of the geological data collected is recorded, and from which other maps may be compiled; convenient field maps upon which the field data may be quickly recorded and the exact localities at which notes are taken or specimens collected may be shown; easy correlation of field maps and notes; and notes which are readily indexed.

The original topographic sheets are photographically enlarged twice linearly for field use. The field maps are printed on linen and the "office" maps, upon which the field data are compiled, are printed on paper. For convenience in handling, each map sheet is divided, as is a common practice, on the meridians and parallels into nine parts, each part being a five- or ten-minute "rectangle." These rectangles are numbered, as in Fig. 11; thus with the name of the map sheet any rectangle may be definitely referred to. On the enlarged scales these rectangles are, in the vicinity of the 49th parallel, a little less than 8 in. x 12 in., which is too large to be placed flat in a notebook small enough to be conveniently carried, 4 in. x 6 in. being the size of the field notebook used. Also, too many points would be recorded on such a large map. So each rectangle is cut into four parts, called the northwest, northeast, southwest, and southeast "quadrants." Any one of these quadrants may be referred to; for example, Victoria III. northeast, or abbreviated for notetaking V. III. N. E. On the paper "office maps," which are cut into rectangles and mounted on linen, the subdivision into quadrants is only indicated by light lines. It is desired to have in the field a map at least as large as a rectangle, so the linen quadrants of each rectangle are

bound together with binding tape. This permits the map to be folded and placed in the notebook, where it is held by rubber bands, with any quadrant face out.

Each field geologist has a complete set of linen maps on which to record in the field the data he collects, recorded with a hard lead pencil (4 H is best) but inked every night if possible. Starting from a known point, he follows, more or less closely, a previously outlined traverse to another known point, frequently a point of rendezvous with the geologist in charge. A pacing traverse with compass bearings and aneroid elevations is kept by

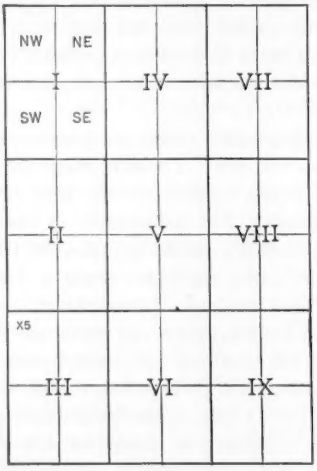

FIG. 11.

means of a tally register, every fourth pace being registered. The number of traverses per unit area is determined by the character of the region and of the geology. Ordinarily the traverses are spaced on the map about half an inch apart. The exact locality at which any notes are made is indicated on the map by a small numbered cross. The crosses in any single quadrant are numbered consecutively. Notes are taken on loose sheets of

paper, held in the notebook by rubber bands. In wet weather the notes are taken on celluloid sheets, and both the sheets and maps are best kept in waterproof covers, such as can be made of sole leather. All notes are headed by a reference to the map sheet, rectangle, quadrant, and point, point × 5 in Fig. 11 being referred to as V. III. N. W. × 5. On the loose sheets are recorded in abbreviated form all the data concerning geology, specimens, photographs, topography, or culture. On the map all outcrops are sketched and contacts drawn.

In camp the abbreviated field notes are rewritten. Those concerning geology are written in the notebook, reference to photographs and specimens being made by consecutive numbers. The data concerning the photographs and specimens are entered in a catalogue notebook or on catalogue cards. Notes on topography and culture, usually concerning changes of or additions to the base map, are recorded in a traverse notebook with a record of the pacing traverse. Usually it is not necessary to keep the pacing traverse except on the loose sheets, because the traverse will be sufficiently well indicated on the map, by the consecutively numbered crosses, little trouble being experienced in tracing the traverses from one quadrant to an adjoining one. All points are transcribed on one of the office maps, which is called the "point map" and which is eventually filed away with the notebooks. Each geologist's points are drawn in a different color. On the "outcrop map" all the geological data, kind of rocks, dips and strikes, faults and fossil localities are recorded. This map shows approximately the outline and kind of outcrops or of areas of numerous outcrops, where the individual outcrops are too many and too small to be mapped separately; the different kinds of superficial deposits; and the contacts of the "bed rock" formations. The probable error of location of these contacts is shown by different kinds of dash and dotted lines, as follows:

Observed contacts.

Probable error of location on the enlarged scale map less than 1/20 of an inch.

Probable error of location on the enlarged scale map less than 1/5 of an inch.

Probable error of location on the enlarged scale map less than 1/5 of an inch.

Known fault, probable error of location on the enlarged scale map less than 1/20 of an inch.

Probable fault, probable error of location on the enlarged scale map less than 1/5 of an inch.

Probable fault, probable error of location on the enlarged scale map more than 1/5 of an inch.

Topographical and cultural changes are recorded on another map.

From the outcrop map a "bed rock map" is prepared and kept up to date as much as possible, as it shows the geological structure more clearly than the outcrop map. If necessary, structure sections also are drawn.

As the notes are written a "date index" is made, the points for each day and the pages for the accompanying notes being recorded in the back of the notebook, as follows:

Aug. 28, 1912.
V. VI. N.W. × 3–10 pp. 6–9.
V. VI. N.E. × 1–9 pp. 9–14.
V. VI. N.W. × 11–18 pp. 15–16.

As soon as each notebook is filled, a "point index" of the book is made, grouping all the points in one quadrant together; for example:

Victoria VI. N.W.
× 1–2 pp. 3–4.
× 3–10 pp. 6–9.
× 11–18 pp. 15–16.

At the end of the season a complete index of all the points is made.

The geologist in charge makes also a "subject index" of all the notes on catalogue or index cards. On these cards the notes are

not transcribed, but merely the point numbers, the notebook, and the page on which the note is to be found, are recorded. Thus, during the writing of the report, the writer has ready access to all the notes bearing on any subject.

This system requires considerable night work or else days off from field work, especially on the part of the chief geologist. However, the accuracy and completeness of the observations and the time eventually saved by having readily accessible and well indexed notes—for with the point map and indexes any note on any location or on any subject can be quickly found—more than offset the extra time spent at night or the time lost from actual field work. It has been found that locations can be fixed more quickly and more accurately on the map and can be referred to more quickly by this method than by the system of coördinates more commonly used. It is unlike the coördinate system in that the localities at which notes were made can not be relocated if the map accompanying the notes is lost. The chance of loss is, however, very slight if the "point map" and linen field maps are sent back to the office by different routes and by different carriers.

CHARLES H. CLAPP.

METHODS OF FIELD WORK IN THE PHOSPHATE DISTRICTS OF IDAHO, MONTANA, WYOMING AND UTAH.

Sir: The investigation of the western phosphate fields affords an example of geologic work in which the accuracy of the location of the data, incidental to the classification of the public lands, is necessarily greater than in general geologic work where ordinarily a close approximation suffices. The problem involves the location of the trace of the outcrop of a definite economic horizon in a folded and faulted series of sedimentary rocks, together with the estimation of its position to a depth of 5000 feet. The region is mountainous with a relief of about 3500 feet.

I propose to comment briefly on the instruments and instrumental methods used, the matter of preparation for the field, and

field practice, and to exhibit a form of outline for notes on sedimentary rocks.

Instrumental Methods.—In the instrumental methods which have been employed an attempt has been made to attain the degree of precision warranted by the scale of the work in hand. The instrumental methods are to that extent precise methods. Often, however, approximate methods are adequate for portions of the detailed work, and conversely precise methods are occasionally essential to portions of the reconnaissance work.

The precise methods are applied, for example, to the location of the phosphate outcrop in reference to legal monuments (section corners), and to the mapping of its trace across forty-acre and other legal tracts. The accurate location of certain formation boundaries and the careful measurement of the intervening stratigraphic distances which are needed in calculations of the depth of the phosphate may be cited as of the same sort. The precise methods employed involve plane table work over the topographic base or over a geographic projection by triangulation or by stadia traverses, and are mainly derived from the plane table methods which have been developed by the topographers of the United States Geological Survey, working in the western states. The instruments used with one or two exceptions are those in use at the present time by the topographic branch of the Survey and were designed by members of that branch.

The Johnson plane table with a board 18 inches square has been found especially suitable because of its stability, ease of leveling and orientation. A complete description of this instrument will be found on page 71 of U. S. Geological Survey Bulletin 307. The instrument is carried on the shoulder, either when on foot or horseback, but in places where a need is felt for a lighter instrument, the traverse table with "Bumstead head," described on page 77 of the same bulletin, or an adaptation of a photographic tripod such as suggested by F. L. Ransome[1] suffices.

[1] Ransome, F. L., "The Plane Table in Geologic Mapping," Econ. Geol., Vol. 7, No. 2, 1912, pp. 113–119.

The use of tables lighter and less complete than the Johnson has been found by the writer a source of inconvenience on account of vibration in windy weather, loss of time in leveling, and the danger of the board moving, even momentarily, out of correct orientation.

The fact that the geologist has to "pack" or carry numerous instruments with which the topographer is not burdened has made it undesirable to adopt the large telescopic alidade generally used in topographic work.

A convenient and very satisfactory instrument is that known as the Gale telescopic alidade, made by the Bausch and Lomb Optical Company and designed by H. S. Gale of the geologic branch. This instrument is compact, light, strong, and durable. It is carried in a sling case about one-fourth of the size necessary for the type of instrument in general use. The Gale instrument will do all the work of the larger alidade, is less expensive, and less apt to be injured in the field.

The telescopic alidade permits the use of the stadia method of measuring distances. For this the services of a rodman are necessary, and in most cases the geologist will find it convenient to act in this capacity while his assistant is placed in charge of the plane table. The stadia method is especially useful in a region where many observations are grouped in a small area or accurately measured traverses are a necessity.

Preparation for the Field.—The character of the preparation for the field depends on whether or not a topographic map previously prepared is available for the region to be geologically surveyed. When such map is available it has been found that photolithographic copies of the topographic field sheets on the original scale upon double mounted Paragon paper which has been calendered prior to printing, are the most satisfactory for the use of the plane table. The photolithographic copies are slightly more expensive than photographs, but the latter have often been found inaccurate in scale, probably because of the irregular shrinking of the paper when drying. The drawing paper copies are more permanent for record purposes than photo-

graphs, and it is easier to make any necessary changes in the topography. Lithographic copies are also printed on a thin tough paper which takes ink well. These may either be folded or dissected to convenient size and mounted on cloth so that they fold and may be carried in the notebook for approximate mapping.

When a topographic map is not available the procedure varies as the work is to be of a detailed or of a reconnaissance character. If of the latter kind and the longitude and latitude of points in or bordering on the region to be surveyed are on record, this information is plotted upon a geographic net of the area which has been laid out upon double mounted plane table paper, according to the data available in Bulletin No. 234, U. S. Geological Survey. The scale of the net is governed by the size of the area to be examined and the size of the plane table board convenient. 1:250,000 permits the mapping of a degree sheet on an 18 by 24 inch board. The known points are then platted in their respective positions and serve as primary control or as a base for expanding such control according to the number of points available. When, however, a small area is to be examined in detail the matter of longitude and latitude is of slight consequence, and the details of the public land surveys, railroad or canal alignments, and county road maps are of more importance. The control is in this case built up in the field by expanding a triangulation net from a measured base.

Field Practice.—The first step in plane table work in the field in a region where a topographic map is available is the determination of the existing magnetic declination in order to be able to make a preliminary orientation of the map by means of the needle. This is done by occupying one of the original primary topographic stations and orienting upon a distant primary station, of course selecting points which are shown on the map in use. All other stations will then be in correct orientation if the mapping is correct and there has been no differential alteration of the scale in reproduction. The needle on the alidade is released and the instrument rotated until a zero reading is obtained. A pencil line is then ruled which represents the local magnetic meridian

unless exceptional conditions obtain. It is well to note that in some areas more than one magnetic line is essential, as it will be found in later "set-ups" with the orientation given by this line that re-section from the primary points yields "triangles of error" which indicate that the previously determined magnetic line does not hold for the new station. In some cases it has been found that one magnetic line will yield good intersections only when the surficial rocks are of the same general lithologic character as those of the station for which the magnetic line was originally determined. This may of course be due to deep-seated causes, but a magnetic line for sandstone and another for limestone has so often been found expedient that it appears all but certain to the writer that some such correlated control exists. In other cases the magnetic variation of a region may lack such regularity and it is found necessary to make a solution of the three-point problem for each set-up. In such a region considerable time can be saved by increasing the amount of locations by the stadia method.

The Bohnenberger solution[1] of the three-point problem is one of the easiest to remember and to perform. After obtaining a triangle of error rotate the table slightly and resect from the same points, then connect the similar angles of the two triangles, since it is known that they lie on a circle which passes through the point sought, and the circle in most cases is so large that the chord closely approximates the arc. The connecting lines will intersect in the point sought unless two of the known stations are much nearer to the station occupied than the third; in such case the construction lines form a triangle of error. This difficulty is avoided by a judicious selection of signals or by setting the board so that the triangles of error used in making the construction are small. In the case where the station sought is centrally situated in reference to the three known stations one of the triangles falls within the other and the point sought is the common center. In such a case the process is shortened by finding the center of the first triangle by construction. Ransome[2]

[1] Bauemfeind, "Vermessungskunde," 3d ed., 1869, p. 542.

[2] Ransome, F. L., *loc. cit.*, p. 116.

and Wegemann[1] have recently described other methods of solving the three-point problem. After the point sought or the actual position of the station on the map is determined, the next step is to revolve the plane table board into correct orientation by placing the alidade on the line between the point found and the known station and turning the board until the latter coincides with the vertical axis of the instrument. All other primary points will "come in" if the solution is a correct one, and the orientation may be used for intersection.

When the known stations and the point occupied all lie on or near the circumference of a circle, a series of intersections will be obtained with different orientations of the board and the point sought is indeterminate. This difficulty is overcome by discarding one or two of the known stations and resecting from other known stations.

The actual locations made by the topographer are often shown on the engraved map by dots printed in the contour color; these make apparent the local quality of the map and are of great aid to the geologist in selecting stations by inspection.

In regions where a topographic map is not available it is necessary to develop a control. A base is measured either by stadia, taping, or by a wheel traverse. In some places it is convenient and satisfactory to accept a section line and section corners as the end stations. It is of course essential to select the base line so that the end stations are visible from each other, in order to insure a true orientation. One end of the base line is occupied. The position and orientation of the base on the plat is arbitrarily established by ruling a long line, and after the position of the station occupied is selected, then directions of sight are recorded to the objects which are to be used in building up the control, rock piles, signal tripods, houses, trees, etc. The base, if its length is already determined, is laid off on the plat on the scale which has been arbitrarily selected for the work. The second station occupied is generally the other end of the base. The board is correctly oriented by setting the alidade on the extended

[1] Wegemann, Carroll H., ECON. GEOL., Vol. 7, 1912, p. 629.

base line and rotating the board until the signal at the first station "comes in." It is, however, not essential that both ends of the base be occupied, providing that the foresight line taken to the station to be occupied second is sufficiently long to permit a close setting of the alidade. The orientation of the board having been correctly established by back sight, the position of the second station is found by resection from the other end of the base. This found, the next procedure is to intersect the sight lines from the first station. In choosing the third station it is best to select one where the angle of intersection lies near to a perpendicular drawn to the middle of the base line. Such a station is occupied, the plat is oriented by back sight, and sights are then taken to the stations which have already been intersected by the other sights. If the work has been correctly and carefully done all three lines will intersect without making even the smallest triangle. If, however, a triangle is found, the orientation at either the second or third stations was incorrect and it is necessary to repeat the work until the error is eliminated. When a group of stations, or the beginning of the control has been established by a satisfactory intersection of sights from three stations, the position of this station is always accepted as final, and apparent errors observed from new stations show that the latter must be reëstablished. Any station, once established, may be used in extending the control. The orientation of the plane table is preferably made by back sight and the extension of primary control from stations located by three-point solution is avoided because of the possible existence of slight errors of orientation.

The use of a needle for pricking stations and as a turning post for the alidade is, except when used with extreme care, a source of error, and has always been found a matter of inconvenience. Stations are recorded with a sharp-pointed hard pencil and one soon finds it easy to turn the alidade on such a point.

Notes.—The method of recording notes which is used is a serial one, each observer's notes being numbered consecutively beginning with 1. The note numbers apply also to fossil and lithologic collections and to phosphate samples. The Geological

Survey loose-leaf notebook is convenient for assembling in the office the notes of the field season. The following printed outline expedites the taking of notes on sedimentary rocks and is convenient for office reference. The blanks are filled out as indicated and ample space for continuing notes is afforded by the back of the preceding page.

R. 247 *T.* 2 S. *R.* 9 W. *sec.* 9 N.W.¼ N.E.¼
Strike N. 70° *E. W.*
Dip 32° *N. E. S. W. Elevation* 5725 Bar.
Lithologic specimens. Phosphate with reddish tinge. (This station is on a sharp point not shown on the topographic map.)
~~*Fossil Lot.*~~
Samples for analysis. Phosphate float composite.
Formation. Phosphate shales 20 dp. across w. cht. weathered brown on S. and 1 s. gray free from cht. on N.

The stations on the map are identified by the note numbers to which the observer's letter is prefixed. The public land designation of the tract in which the station is located is inserted in the note and serves as a means of cross reference from the note to the map.

The notes concerning fossil lots, specimens and phosphate samples are made easy to pick up for listing by placing check marks in the margin.

R. W. RICHARDS.

REVIEWS

A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas. By J. A. UDDEN and DRURY MCN. PHILLIPS. Bulletin of the University of Texas, No. 246, Sept. 8, 1912.

The area described in this report is about 60 miles long in an east-west direction and about 30 miles wide and the Electra and Petrolia oil fields, which have recently been the scenes of extensive development, separated by an interval of 40 miles, lie near the western and eastern boundaries of the area respectively. The report may be divided into three parts: (1) that treating the stratigraphy and major structure as inferred from surface exposures; (2) that treating the stratigraphy and major structure as inferred from well data; and (3) that considering well data as bearing on minor structures.

Anyone familiar with the topography, rock exposures, and stratigraphy of the region involved in this study will appreciate the difficulties that must be encountered in any attempt to decipher minor structures, especially such as may have a bearing upon the accumulation of oil and gas. This, taken with the relative absence of knowledge in general concerning several of the factors bearing upon such problems, should temper any critical attitude with generosity. While the reviewer recognizes much that is commendable as indicating extremely careful work on the part of the authors, the report gives a general impression of not being well balanced. It contains 291 pages, of which 164 are devoted to detailed well records. Of the 118 pages of descriptive matter, 92 contain descriptions of factors bearing upon the major structure of the region and though 18 pages deal with minor or retaining structures and the oil and gas sands, much of this space presents general rather than specific information.

With regard to the first part of the report, field observations were apparently recorded on a land map though no mention is specifically made of the fact, and in making dip observations "use was made of the common hand level . . . and in some places use was made of the aneroid" (p. 44). Whether or not the plane-table was considered in this connection is not stated, but the omission emphasizes the existence of widespread ignorance of the great use to which this instrument, together

with the telescopic alidade, may be put, especially under such conditions as this region presents. Not only may it be used to traverse the outcrop of a bed with accuracy, but where three points are located on a bed, the true strike and dip may be accurately determined, even in the case of beds of low dip. This feature is emphasized because the authors use inferred dips and strikes to determine the major structure of the region, and though it would be rash to state that they have not discriminated closely between the inclination of a bed along a chance badland section and the true dip, the field methods employed and the omission of any discussion relative to the significance of outcrop observations make the suspicion plausible.

The descriptions of lithology are good and show close observation, but it is a surprise to find no mention of baritic concretions which are abundant in every badlands area near Electra. Careful observations on cross-bedding have been taken and an attempt has been made to ascertain the direction of the source of the sediments, by comparing the observations on the direction of "slants" (inclination of the cross-bedding laminae from the horizontal) so as to obtain a resultant. This resultant is considered to indicate approximately the direction toward which sediments were moving and which in this case is found to be from the northeast, east, or southeast. The method of finding the resultant is not above criticism in that it gives the same value to a number of observations within a small area that it gives to an equal number within a very large area. The same criticism also applies to the method used in comparing the stratigraphic section at Electra with that at Petrolia. In this case the components of observed dips along a line between the two points are determined and summated with the result that an average dip is inferred.

Especially interesting and, in view of the poor character of the well records, valuable, is the study of the driller's use of terms. The most valuable feature of the report and that showing most careful and diligent work is the portion dealing with the search for fossils and unusual lithologic characteristics of material taken from the wells during drilling. For this work the authors are to be highly commended and it appears to the present reviewer that it would have been justifiable to publish fully the methods employed in this work. The third portion of the report, dealing with retaining structures and the sands, is not so fully treated as is justified. A map on a small scale shows the inferred structure of the oil sand at Petrolia. There are, however, no statements to indicate that the well records of the Electra field, of which there are far more than at Petrolia, have been closely correlated by determining accurately the elevations of the wells. Several plates have been prepared indicating a correlation of the sands, a method which is of value

largely to compare complete stratigraphic records, but of very questionable value as compared to the contour method, in inferring the structure of sands.

The proof reading has been careless in places. On page 17 it is stated that "about 73 per cent. of the bulk of the shales of the exposed Wichita formation consists of greenish, bluish or light gray shale, and about 13 per cent. consists of alternating layers of red and gray shale," whereas the tables presented show that these figures have been reversed.

In conclusion, the report is a distinct and valuable contribution to the knowledge of Pennsylvanian and Permian stratigraphy of the southwest, but it fails to fulfil completely the purpose of the authors that "the present study . . . was undertaken with the purpose of learning the physical conditions which have brought about the accumulation of oil and gas in the Pennsylvanian sediments in Wichita and Clay counties in the north part of the state."

D. F. HEWETT.

Copper-nickel Deposits of the Insizwa, Mount Ayliff, East Griyualand. By A. L. DUTOIT. Dept. of Mines, Cape of Good Hope, 15th Annual Report (1910), 1911, pp. 110–142.

An interesting district, similar to that of Sudbury, has recently been described in Cape Colony. The Karroo sandstones and shales, near the Natal boundary, are intruded by sheets of dolerite, olivine gabbro and norite, which have induced intense contact metamorphism in the sediments. Copper-nickel ores with some platinum are found close to the contact, impregnating the latter to some extent, but becoming more abundant in, and sometimes restricted to the igneous rock of which sulphides appear to be original constituents. The ore contains abundant pyrrhotite, with chalcopyrite and pentlandite. There is a little bornite and niccolite, probably also sperrylite, and native platinum has been found in a fragment of ilmenite from the district. The copper content varies from 1.2 to 19.3 per cent., that of nickel from 0.6 to 7.3 per cent. The highest platinum content is 4 ounces 19 dws. per ton, the lowest 12 grains, average of 14 assays being 2 dws. 15 grains. There are traces of cobalt, gold, silver and osmiridium. Trial shipments of 5 tons gave 6 grains of gold per ton, 10 dws. silver, 5.90 per cent. nickel, and 3.40 per cent. copper.

Small dikes of quartz diorite or microgranite cut sediments and gabbro near the contact. Chalcopyrite and pyrrhotite are found disseminated in the hornfels as well as in the intrusive. In the gabbro and dolerite iron ores are scanty; they are mostly ilmenite. The silica is from 43 to 50 per cent., potash 0.08–0.35 per cent., soda 0.10–1.35 per cent., FeO 7 to 12 per cent., alumina 4–15 per cent.

Metamorphism to hornfels extends for 400 feet above and 200 feet below the sill, which is a basin-shaped sheet about 3,000 feet thick and 11 miles in diameter; mineralization is confined to lower contact. There is some lime silicate rock with much hornfels. In both, but especially in the latter, are irregular patches of chalcopyrite and pyrite associated with epidote, garnet and chlorite; there are also needles of tourmaline. The ores in the igneous rock are never more than a few feet away from the lower contact. The order of succession of the ores is: chalcopyrite, pentlandite, pyrrhotite, or exactly the reverse of the order obtained by Knight and Campbell in their studies of the Sudbury ores.

The sulphides separated from the magma during the late epoch of consolidation and they were not introduced by aqueous or hydrothermal agencies at some subsequent period.

The olivines show idiomorphic outlines and are surrounded by ore. Augite and enstatite also idiomorphic in contact with the ores and the latter are moulded on faces of the plagioclase feldspars and have frequently formed in triangular spaces between the feldspars. Magnetite is enclosed in sulphides. Biotite is more intimately associated with the ores and may in part have crystallized with them. All silicate minerals are fresh and unaltered. No films of ore occur along cracks or fissures. The acid microgranite veins also contain specks of ores.

In one lime silicate contact rock the sulphide ores enclose magnetite, are moulded on diopside, but are included in wollastonite, which was the last mineral to form. There is every stage from a gabbro or norite with minute scattered particles of ore to an almost pure ore with some silicates scattered through it. The ores form sheet-like bodies running along or nearly parallel to the contact and grading into gabbro. They are rarely more than one foot thick, but the gabbro is often rich in disseminated sulphides.

The sheet carries 43 per cent. silica at the base, 48 per cent. half way up and 50 per cent. at the summit, thus showing a differentiation by gravitation settling.

In Namagualand copper ores (bornite and chalcopyrite) are scattered through hypersthene-bearing dikes as primary constituents.

W. LINDGREN.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

ADOLPH KNOPF AND J. B. UMPLEBY.

METALLIFEROUS DEPOSITS.

BISMUTH.

Die Wismutgänge von Aljin-Dol und Jasikova. By M. LAZAREVIC and E. KITTL. Zeit. pr. Geol., 1912, pp. 280–287.

The bismuth-bearing veins of these Servian localities are inclosed in gabbro, and consist of bismuthinite, pyrite, and chalcopyrite in a gangue of siderite and quartz. K.

COPPER.

Die Enargit-Covellin-Lagerstätte von Cuka-Dulkan bei Bor in Ostserbien. By M. LAZAREVIC. Zeit. pr. Geol., 1912, pp. 337–370.

The normal country rock in which the ore deposit is inclosed is a zeolitic propylitized andesite; near the ore it is kaolinized. The primary minerals of the ore body are enargite, pyrite, quartz, and barite; the secondary minerals are covellite and enargite, which form veinlets traversing the earlier minerals. K.

The Geology of the Dun Mountain Subdivision, Nelson. By J. M. BELL, E. DE COUREY CLARKE, and PATRICK MARSHALL. Bull. New Zealand Dept. of Mines. No. 12 (new series), Wellington, 1911. 71 pp.

The original copper-bearing mineral of the lodes of the Dun Mountain Subdivision apparently consisted of cupriferous pyrrhotite, containing traces of gold, silver, cobalt, and nickel. The lodes all cut basic or ultra-basic rocks, which near the ore bodies have been commonly altered to serpentine. U.

Die Kupfererz und Limonit-Lagerstätten von Majdan-Pek in Serbien. By B. A. WENDEBORN. Zeit. pr. Geol., 1912, pp. 266–280.

The ore bodies occur in andesite or at the contact of the andesite and Cretaceous limestone.

Die Wirtschaftliche Bedeutung der Kupfererzlagerstätten der Welt. By HANS WENCKER. Bergw. Mitt., 1912, pp. 134–140.

Of particular interest is a world map showing the production of the different districts and their genetic classification. K.

GOLD AND SILVER.

Geology of Harrison Gulch, in Shasta County, California. By H. E. KRAMM. Bull. Am. Inst. Min. Eng. No. 67, 1912, pp. 709–715.

The ore bodies are auriferous quartz veins. K.

Gold Mines in Southern Colombia. By F. P. GAMBA. Bull. Am. Inst. Min. Eng. No. 68, 1912, pp. 853–866.

The auriferous deposits comprise two types: 1, *mantos*, that is, impregnated rocks transformed into saprolitic material; and, 2, veins, more or less regular in form. K.

The Occurrence of Gold in the Eocene Deposits of Texas. By E. T. DUMBLE. Bull. Am. Inst. Min. Eng. No. 70, 1912, pp. 1021–1024.

Placer gold occurs in beds of Eocene age; it was probably derived by erosion from the Llano region. K.

The Wedderburn Gold Field. By O. A. L. WHITELAW. Mem. Geol. Survey Victoria, No. 10, 1911, 38 pages, 24 plates.

Nine tenths of the lode gold has come from the intersections of the otherwise barren quartz lodes with the indicators—black carbonaceous slate layers. Eighteen chemical analyses of indicators and auriferous slates are given. K.

The Yetta and Paramatta Mines, South Australia. By L. K. WARD and R. L. JACK. Rept. Dept. of Mines No. 1, Adelaide, 1912, 18 pp. U.

IRON.

The Bearing of the Theories of the Origin of Magnetic Iron-Ores on their Possible Extent. By FRANK L. NASON. Bull. Am. Inst. Min. Eng. No. 67, 1912, pp. 694–708. K.

La Composition Mineralogique de Quelques Minettes. By L. BLUM. Annal. Soc. Geol. Belgique, Vol. 38, 1912, pp. 338–345.

Gives the chemical composition and computed mineral composition of certain minettes (iron ores). K.

Die Erzlagerstätten von Traversella im Piedmont, Italien. By FR. C. MULLER. Zeit. pr. Geol., 1912, pp. 209–240.

The ore deposits consist principally of contact-metamorphic bodies of magnetite situated at the intrusive contact of diorite and carbonate rocks. The associated magnesium silicate contact-metamorphic rocks were serpentinized by solutions accompanying or immediately following the ore-bearing solutions. K.

Note sur Quelques Corps Secondaires des Minettes. By L. BLUM. Annal. Soc. Geol. Belgique, Vol. 38, 1912, pp. 335–339.

Discusses the presence of copper, nickel, arsenic, and alkalis in the minette iron ores. K.

Progress of Opinion as to the Origin of the Lake Superior Iron Ores. By N. H. WINCHELL. Bull. Geol. Soc. America, Vol. 23, 1912, pp. 317–328. K.

La Question du Minerai de Fer. By A. DALMER. Annal. de Mines de Belgique, Vol. 17, 1912, pp. 851–940.

An inquiry concerning the cause of the decadent state of the exploitation of the numerous iron ore deposits of Belgium. K.

Roteisensteinlager in Asturien. By PAUL GROSCH. Zeit. pr. Geol., 1912, pp. 201–205.

The iron ore deposits of Asturia, Spain, occur as persistent beds interstratified with Devonian rocks; they are regarded as of sedimentary origin. K.

The Ta-yeh Iron-Ore Deposits, Hu-Pei Province, China. By C. M. WELD. Bull. Am. Inst. Min. Eng. No. 70, 1912, pp. 1059–1069.

The deposits are regarded as analogues of the deposits at Iron Springs District, Utah, described by Leith and Harder. K.

A Titaniferous Iron Ore Deposit in Boulder County, Colo. By E. P. JENNINGS. Bull. Am. Inst. Min. Eng. No. 70, 1912, pp. 1045–1056.

The principal ore deposit is a pyroxene magnetite-biotite dike, 250 feet wide, which traverses an orthoclase-biotite gabbro. The ore consists of an intergrowth of titaniferous magnetite and pyroxene, with accessory spinel, apatite, and biotite. Is commercially valueless, but interesting scientifically. K.

LEAD AND ZINC.

Lead in 1911. Smelter Production. By C. E. SIEBENTHAL. Adv. Ch. Min. Res. U. S. Geol. Survey, 1912, 41 pp.

The domestic production of lead in 1911 exceeded that in 1910 by a little over 5 per cent., due to increased mining activity, principally in Missouri and Idaho. One new smelter was constructed and construction started on a new refinery. U.

Preliminary Report on the Lead and Zinc of Oklahoma. By L. C. SNIDER. Bull. Oklahoma Geol. Survey No. 9, 1912, 97 pp.

Consists largely of a compilation of existing literature. K.

Das Unterdevon im Bensberger Erzdistrikt and seine Beziehungen zu den Blei-Zinkerzgängen. By V. ZELENY. Archiv. für Lagerstätten-Forschung, Heft 7 König. Preuss. Geol. Landesanstalt, Berlin, 1912, 102 pages, 1 plate.

The commercially important minerals are sphalerite, galena, chalcopyrite, and siderite. The ores occupy fault fissures along which considerable displacement had taken place. The nature of the enclosing wall rock exerted an important influence on the metalliferous filling of the lodes. K.

Zinc and Cadmium in 1911. Smelter Production. By C. E. SIEBENTHAL. Adv. Ch. Min. Res. U. S. Geol. Survey, 1912, 54 pp.

The report includes figures of production, tables of imports and exports of spelter and of zinc ore, a comparison of mine and smelter returns, a list of zinc smelters, a brief review of the advance in the treatment of zinc ores, and a summary of the domestic and foreign conditions of the industry. U.

The Zinc Deposits of Northeastern Tennessee. By A. H. PURDUE. Bull. Tenn. Geol. Survey No. 14, Nashville, 1912, 69 pp.

The zinc ores of northeastern Tennessee occur only in the Knox dolomite, which, since other formations present conditions equally favorable for their occurrence, leads to the belief that the zinc was originally deposited with that formation. U.

TIN.

Bibliography of the Geology and Mineralogy of Tin. By FRANK L. HESS and EVA HESS. Smithsonian Misc. Coll., Vol. 58, No. 2, 1912, 408 pp.

The bibliography is classified as follows: I. By counties; II. General; III. History; IV. Metallurgy and chemistry; V. Mineralogy; VI. Mining and milling; VII. Statistics. "In digesting articles upon the geology of tin deposits it has been aimed to give, where possible, (*a*) the country rocks, (*b*) age, (*c*) origin of the deposits, (*d*) accompanying minerals, (*e*) economic importance, and (*f*) other details of value." K.

Notes on the Nature and Origin of the Vredehoek Tin Deposits, Capetown. By E. H. NELLMAPIUS. Trans. Geol. Soc. S. Africa, Vol. 15, Johannesburg, 1912, pp. 1–3.

NON-METALLIC PRODUCTS.

BUILDING STONE.

Building and Ornamental Stones of Canada. By WM. A. PARKS. Vol. 1, Canada Dept. of Mines, Mines Branch, Ottawa, 1912, 365 pp.

The volume contains a systematic description of the different building and ornamental stones occurring in that part of the province of Ontario which lies south of the Ottawa and French rivers. U.

Der "Hydratwassergehalt" im Trass. By F. TANNHÄUSER. Bautech. Gesteinsuntersuchungen, Vol. 2, 1911, pp. 35–43.

The water content of trass furnishes (for the trasses investigated) a good index of their hydraulic properties. K.

Systematische Untersuchung der Gesteins-Materialien alter Bauwerke—3. Das Baugestein im Strassburger Münster. By J. HIRSCHWALD. Bautech. Gesteinsuntersuchungen, Vol. 2, 1911, pp. 19–34.

The Strassburg cathedral was commenced in 1015 and completed in 1439. The building stones have therefore been subjected to weathering for periods of 500 to 900 years. Systematic investigation of weathered and unweathered stone was made by the author by means of thin sections, water absorption tests, etc. K.

Theorie und Praxis der Bauwissenschaftlichen Gesteinsuntersuchungen. By J. HIRSCHWALD. Bautech. Gesteinsuntersuchungen, Vol. 2, 1911, No. 2, pp. 1–18.

Discusses the theory and practice of testing building stones, and advocates certain reforms in the methods currently employed in testing laboratories. K.

COAL.

Die Diluvialen Kohlen in der Schweiz. By FR. C. MULLER. Zeit. pr. Geol., 1912, pp. 289–300.

The coal belongs to the lignite class and is of Pleistocene interglacial age. K.

Das Volumenverhältnis zwischen Moortorf und daraus Resultierende Autochthoner Humusbraunkohle. By FRIEDERICH GLÖCKNER. Zeit. pr. Geol., 1912, pp. 371–374.

It is concluded from geologic evidence that the original thickness of the layer of peat-bog material was 2.5 times that of the present thickness of the resulting coal bed. K.

KAOLIN.

Die Chemie des Kaolins. By H. STREMME. Fortschritte der Mineral., Krist., und Petrographie, Vol. 2, 1912, pp. 87–128.

Discusses composition, water content, solubility, behavior toward reagents, transformation into other minerals, artificial production, nomenclature, origin in nature, the question concerning the colloidal character of amorphous kaolin, and the constitution of kaolin. K.

Die Verbreitung der Kaolinlagerstätten in Deutschland. By ALFRED STAHL. Archiv. für. Lagerstätten-forschung, Heft 12, König. Preuss. Geol. Landesanstalt, Berlin, 1912, 136 pages, 1 plate.

The principal endeavor of this report has been to study the distribution of the kaolin deposits of Germany in order to draw conclusions concerning their genesis. It is concluded that kaolinization is due to the action of solutions carrying carbonic acid. K.

OIL AND GAS.

Das Asphaltkalkgebiet des Pescaratales am Nordabhange der Majella (Abruzzen). By GEORG THIEL. Zeit. pr. Geol., 1912, pp. 169–196.

Gives the stratigraphy and paleontology of the Tertiary rocks in which the asphalt occurs; describes the asphalt deposits, discusses their origin, and gives statistics of production. The genetic conclusion is reached that the deposits were formed by the impregnation of limestones by thinly fluid hydrocarbons, whose evaporation and oxidation residuum constitutes the asphalt. K.

Die Naphthalagerstätten der Umgebung von Solotwina. By ERICH SIEGFRIED. Petroleum, 1912, pp. 1049–1053, 1106–1118.

Is a contribution to the tectonics of the Carpathian borderland in east Galicia. K.

Die Oelfelder Sachalins. Petroleum, 1912, pp. 887–891. K.

Oil and Gas Development in North-central Oklahoma. By ROBERT H. WOOD. Bull. U. S. Geol. Survey No. 531-*B*, 1912, 31 pp.

The formations containing the sands, which are productive in the main field to the east, dip beneath this area, and at no place attain a depth greater than 4,200 feet. Locally these beds present anticlinal folds, which leads to the conclusion that the area is one to justify exploratory work. U.

Ueber die Erdöle aus Süd-Bolivien. By M. RAKUSIN. Petroleum, 1912, pp. 985–987. K.

Ueber die Naphthavorkommen auf Russisch-Sachalin. By K. N. TULSCHINSKY. Petroleum, 1912, pp. 987–993. K.

SALINES.

Petrographisch-geologische Untersuchung des Salzgebirges im Werra-Fulda-Gebiete der deutschen Kalisalzlagerstätten. By KURT BECK. Zeit. pr. Geol., 1912, pp. 133–158.

The Werra-Fulda region constitutes the southwestern extremity of the German Zechstein Salt Sea. Two beds of potassium salts occur:

a lower bed averaging 2 to 5 meters in thickness, and an upper bed averaging 2 to 2.5 meters. They are separated by a 50-meter bed of rock salt. In this respect they differ from the normal Stassfurt section, according to which the potassium salt beds should be separated by layers of saliferous shale and anhydrite. K.

Studien über den Bau von Salzmassen. Physikalische Kräfte im Salz. By RICHARD LACHMANN. Kali, 1912, pp. 342–353, 366–375, 398–400, 418–431. K.

Ueber die Physikalischen Bedingungen bei den Salzablagerungen zur Zeit ihrer Bildung und Entwicklung. By SVANTE ARRHENIUS. Kali, 1912, pp. 361–365. K.

Ueber Salztone und Plattendolomite im Bereiche der Norddeutschen Kalisalzlagerstätten. By CARL REIDEMEISTER. Kali, 1912, pp. 226–234, 295–301. K.

WATER RESOURCES.

An Intensive Study of the Water Resources of a Part of Owens Valley, Cal. By C. H. LEE. W.-S. Paper U. S. Geol. Survey No. 294, 1912, 135 pp. U.

Surface Water Supply of the United States, 1910, Part IV., St. Lawrence River Basin. By C. C. COVERT, A. H. HORTON, and R. H. BOLSTER. W.-S. Paper U. S. Geol. Survey No. 284, 1912, 125 pp. U.

Surface Water Supply of the United States, 1910, Part X., The Great Basin. By E. C. LA RUE, F. F. HENSHAW, and E. A. PORTER. W.-S. Paper U. S. Geol. Survey No. 290, 1912, 264 pp. U.

Surface Water Supply of the United States, 1911, Part IV., St. Lawrence River Basin. By C. C. COVERT and R. H. BOLSTER. W.-S. Paper U. S. Geol. Survey No. 304, 1912, 99 pp. U.

Water Resources of California, Part I., Stream Measurements in Sacramento River Basin. By H. D. MCGLASHAN and F. F. HENSHAW. W.-S. Paper U. S. Geol. Survey No. 298, 1912, 411 pp.

The United States Geological Survey now has available records of flow at 289 points on California streams. This information is to be made available by six reports which will bear the numbers 295 to 300 inclusive. U.

REGIONAL.

The Bonnifield Region, Alaska. By STEPHEN R. CAPPS. Bull. U. S. Geol. Survey No. 501, 1912, 64 pages, 8 plates and 3 figures.

The mineral resources comprise placer and lode gold, and coal. The coal is an Eocene lignite and the reserves are estimated to contain ten billion tons. K.

The District of Patricia. By W. G. MILLER. Bureau of Mines, Vol. 21, Part II., Toronto, 192 pp.

The report is a compilation of geologic and geographic knowledge of a large area recently added to the province of Ontario. U.

The Geology and Mineral Resources of the Aroroy District, Masbate. By H. G. FERGUSON. The Philippine Jour. of Sci., Vol. 6, Manila, 1911, pp. 397–426. U.

The Geology of the Murchison Range and District. By A. L. HALL. Memoir Geol. Survey, Union of South Africa No. 6, Pretoria, 1912, 186 pp. U.

Geological Reconnaissance of Mindanao and Sulu: III. General and Economic Geology. By W. D. SMITH. The Philippine Jour. of Sci., Vol. 4, No. 5, Manila, 1911, pp. 359–394. U.

Headwater Regions of Gulkana and Susitna Rivers, Alaska. By F. H. MOFFIT. Bull. U. S. Geol. Survey No. 498, 1912, 82 pp.

The mineralization of this region is genetically related to granitic intrusives which cut Triassic and Carboniferous sediments. It is from lodes in these sediments that the placer deposits of Valdez Creek and the Chistochina district have been concentrated. U.

The Mining Districts of the Western United States. By JAMES M. HILL, with a Geologic Introduction by WALDEMAR LINDGREN. Bull. U. S. Geol. Survey No. 507, 1912, 309 pp., 16 pl., 1 fig.

This bulletin indexes the 1,479 recognized mining districts of the Western States, groups them by states, shows the position of each on a state map, gives the subnames of the districts, the metals produced, the shipping point, a brief statement of the geologic formation, the kind of deposits, and a bibliography of Survey publications relating to each.

The geologic introduction by Waldemar Lindgren is a digest of present knowledge of the local geology of western ore deposits, treated by states. U.

The St. Helens Mining District. By HORACE V. WINCHELL. Bull. Am. Inst. Min. Eng. No. 70, 1912, pp. 1037–1044.

The absence of quartz float, the lack of gossans, and the tourmaliniferous character of the mineralization would not make the district attractive to the experienced prospector. K.

Ueber Erzlagerstätten in sauren Eruptiv-Gesteinen Deutsch Südwestafrikas. By BERGASSESOR DAHMS. Zeit. pr. Geol., 1912, pp. 240–247.

Describes occurrences of cassiterite, monazite and tantalite, wolframite, molybdenite, and copper ores.

GENERAL AND THEORETIC.

Ein Beitrag zur Genesis der Alpinen Kieslagerstätten. By K. G. REDLICH. Zeit. pr. Geol., 1912, pp. 197–200.

Many of the Alpine sulphide ore bodies, instead of being of sedimentary syngenetic origin, are metamorphic veins in the sense employed by Lindgren. K.

Epigenetische Erzlagerstätten und Eruptivgesteine. By A. BERGEAT. Fortschritte der Mineral., Krist., und Petrographie, Vol. 2, 1912, pp. 9–23.

Classifies epigenetic deposits as perimagmatic and apomagmatic, and discusses their genetic relations. K.

Die Gase im Magma. By PAUL NIGGLI. Centralbl. f. Mineral. Geol. Pal., 1912, pp. 321–338.

The aim of this paper is to apply physical-chemical laws to actual magmatic solutions, *i. e.*, the molten rock-forming minerals plus the originally dissolved gas content. K.

Historische Entwicklung und Definition der Hauptsächlichsten tektonischen Begriffe in Bergbau und Geologie. By ADOLPH KRÜMMER. Zeit. pr. Geol., 1912, pp. 249–265.

Discusses the origin and definition of the principal tectonic terms employed in mining and geology: faulting, folding, overthrust, **shift** fault, and rock cleavage. K.

The Sulphides of Zinc, Cadmium, and Mercury; Their Crystalline Forms and Genetic Conditions. By E. T. ALLEN and J. L. CRENSHAW. Microscopic study by H. E. MERWIN. Am. Journ. Sci., Vol. 34, 1912, pp. 341–396.

The sulphide of zinc, like that of iron, crystallizes in nature in two different crystal systems—sphalerite (isometric) and wurtzite (hexagonal). Sphalerite is stable up to a temperature of 1020°, where it passes into wurtzite. In comparing the genetic relations of sphalerite, wurtzite, cinnabar, and metacinnabar with those of pyrite and marca-

site it is noteworthy that the stable forms (sphalerite, cinnabar, and pyrite) are always obtained by crystallization from alkaline solutions and that the unstable forms are obtained from acid solutions only. U.

Die Tektonik des Emser Gangzuges. By ADOLPH KRÜMMER. Zeit. pr. Geol., 1912, pp. 307–319.

The outcrop of the vein system is traceable, with interruptions, for more than 35 kilometers. Individual veins range up to 10 meters in thickness; exceptionally to 20 meters. The greatest depth obtained is 700 meters. The tectonic features are complex and are discussed in some detail. K.

Ueber die Bildung von Erzlagerstätten durch Magmatische Differentiation. By J. H. L. VOGT. Fortschritte der Mineral., Krist., und Petrographie, Vol. 2, 1912, pp. 24–40.

A short genetic presentation. K.

Ueber Erzsuchen mittels Elektrizität. By O. TRÜSTEDT. Zeit. pr. Geol., 1912, pp. 159–162.

Outlines a method for prospecting concealed metalliferous ore bodies by means of Hertzian waves. K.

UNCLASSIFIED.

An Early Discovery of Fullers' Earth in Arkansas. By J. C. BRANNER. Bull. Am. Inst. Min. Eng. No. 67, 1912, pp. 747–749.

Calls attention to the fact that fullers' earth was known and was already being mined in the State of Arkansas as early as 1891. K.

The Mineral Pigments of Pennsylvania. By B. L. MILLER. Top. and Geol. Surveys of Pennsylvania, Rept. No. 4, Harrisburg, 1911, 95 pp. U.

Das Magnesitvorkommen von Trens bei Sterzing in Tirol. By RICHARD CANAVAL. Zeit. pr. Geol., 1912, pp. 320–325.

The magnesite is regarded as derived from limestone metamorphosed by magnesian solutions emanating from intrusive granite masses, notwithstanding the fact that the deposit contains a chrome mica in some abundance. K.

The Mineral Springs of Saratoga. By JAMES F. KEMP. Bull. New York State Museum No. 159, Albany, 1912, 79 pp.

The author inclines to the belief that the carbonic acid gas, the chlorides, bromides, iodides, fluorides, and sodium carbonate which occur in these springs are of deep-seated origin. U.

Mines and Quarries; General Report with Statistics for 1910. By the CHIEF INSPECTOR OF MINES OF GREAT BRITAIN. London, 1912, 494 pp. U.

The Production of Glass Sand, Other Sands, and Gravel in 1911. By E. F. BURCHARD. Adv. Ch. Min. Res. U. S. Geol. Survey, 1912, 56 pp. U.

The Production of Lime in 1911. By E. F. BURCHARD. Adv. Ch. Min. Res., U. S. Geol. Survey, 1912, 76 pp.

The volume of business transacted by the lime industry in 1911 was a little less than that in 1910. The production is given as 3,392,915 short tons, valued at $13,689,054. U.

Summary Report of the Mines Branch of the Department of Mines of Canada for 1911. Ottawa, 1912, 201 pp. U.

Tests of the Absorptive and Permeable Properties of Portland Cement, Mortars and Concretes, together with Tests of Dampproofing and Waterproofing Compounds and Materials. By R. J. WIG and P. H. BATES. Technologic Paper, U. S. Bureau of Standards, No. 3, Washington, 1912, 127 pp. U.

SCIENTIFIC NOTES AND NEWS[1]

In addition to a geological reconnaissance of central Panay and of the Tayabas oil field, the staff of the Division of Mines of the Bureau of Science, Manila, P. I., is at present engaged on the following engineering projects:

1. The geological examination of central Panay, with particular reference to artesian well conditions.
2. The investigation of a new reservoir for the city of Manila.
3. The investigation of various private quarries and the City Quarry, to determine the most suitable means of securing road metal for the city of Manila.

Professor James F. Kemp delivered recently in the Faculty of Applied Science at McGill University, a short course of lectures on the "Services of Geology to the Mining Industry."

Professor C. K. Leith has given during the winter a six weeks' course in pre-Cambrian and structural geology at the University of Chicago.

At recent meetings of the Geological Society of Washington the following papers have been given:

Sidney Paige: "The Bearing of Pre-Cambrian Structure on the Origin of the Homestake Ore Body."

W. T. Lee: "Recent Discovery of Dinosaur Bones in the Tertiary."

F. H. Knowlton: "A Paleobotanical Study of the Coal-bearing Rocks of the Raton Mesa Region of Colorado and New Mexico."

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

J. T. Singewald, Jr.: "Relations of Ilmenite and Magnetite in Titaniferous Magnetites."

N. H. Darton: "The Construction of a Structure Map of the Northern Anthracite Field."

Chase Palmer and Edson S. Bastin: "Certain Metallic Minerals as Precipitants of Silver and Gold."

J. M. Hill: "The Zinc-lead Deposits of the Yellow Pine District, Nevada."

A. H. Brooks: "The Work of the Alaskan Railroad Commission."

DR. GEORGE GIRTY, paleontologist, with the U. S. Geological Survey, has recently returned to Washington after two months' absence in Italy.

M. J. MUNN has returned from southwestern Oklahoma, where he has been engaged for four months in studying the structure of the region with regard to prospective oil fields. (See page 206.)

E. W. SHAW, of the U. S. Geological Survey, devoted the field season of 1912 to concluding work on the Carlisle (Ill.) quadrangle, after which he spent four months in physiographic studies in the Gulf embayment.

J. H. HANCE, of the U. S. Geological Survey, who has been engaged in saline investigations in Nevada for two years, has returned to Washington.

J. B. TYRRELL has returned to Toronto, after spending two months in London, England.

E. DEK. LEFFINGWELL is in Washington after a residence of about six years on the north coast of Alaska, where he was engaged in geographic, geologic and hydrographic work. This work involved explorations over an area 60 by 120 miles, lying between longitude 142° and 150° west and from latitude 69° to 70° north, with Flaxman Island as a base.

M. R. CAMPBELL, of the U. S. Geological Survey, has recently been in British Columbia on a month's leave of absence.

ROBERT ANDERSON, geologist, of the U. S. Geological Survey, has resigned and will go into private practice in partnership with A. C. Veatch, specializing in the geology of petroleum.

THE U. S. GEOLOGICAL SURVEY has recently issued to the press an advance summary of the results of several months' work in the fall of 1912, by M. J. Munn, in southwestern Oklahoma. The region which was examined lies on the north side of Red River and adjoins the area in Texas in which the new oil fields of Electra, Henrietta and Burkburnett occur. The aim of the reconnaissance was to determine whether the exposures of bed rock sufficiently permitted interpretations of structure to indicate those areas which offered promise of the occurrence of oil and gas pools. The results were definite enough to permit the designation of a number of sections in the twelve townships examined that were structurally favorable. A complete report of the work will soon be issued. The development of the region will be watched with interest as throwing additional light upon the question of the service that may be rendered by a geologist in advance of actual exploration.